

**Radio-  
Electronics**

**RECEIVING**

# **Satellite**

**TELEVISION**

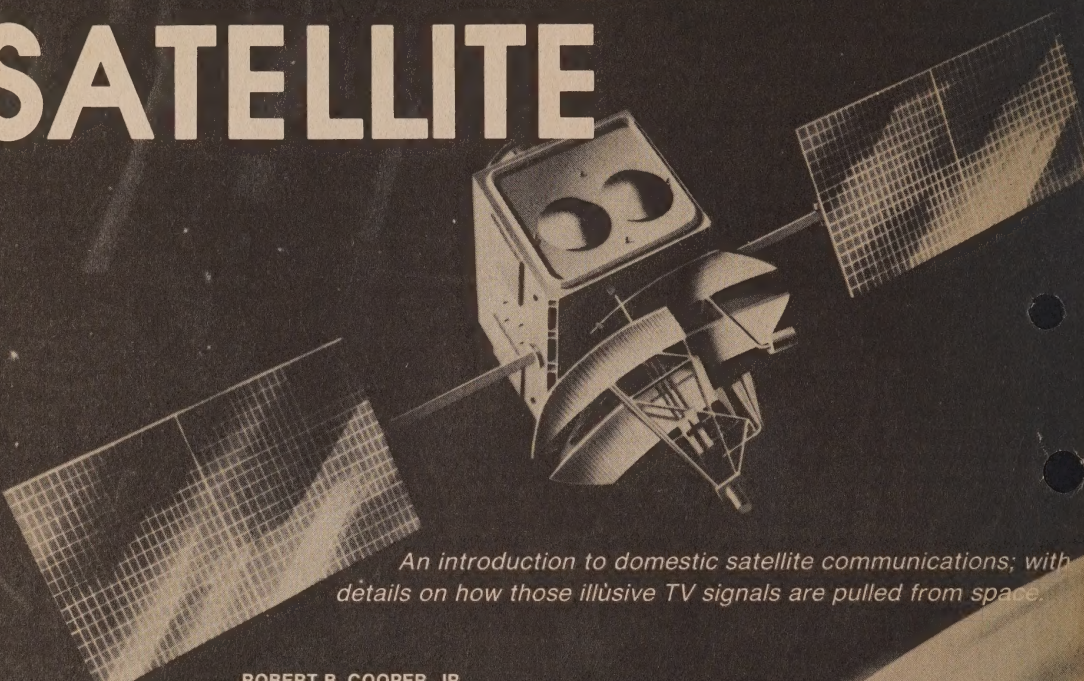


**What's Up There To Watch ★ Is It Legal?**  
**Receiver Characteristics and Specifications**  
**Low Cost Antenna ★ Aiming The Antenna**

**SPECIAL REPRINT**



# Home Reception *via* SATELLITE



*An introduction to domestic satellite communications; with details on how those illusive TV signals are pulled from space.*

ROBERT B. COOPER, JR.

YOU MAY BE TOO YOUNG TO HAVE BEEN A PART OF THE EXCITING 1946-1952 "dawn of television era." I was a youngster in upstate New York who spent his high school years souping up 630-type chassis, building cascade and cascode signal boosters with 6BQ7's and trying out every antenna I could lay my design hands on—from stacked 10-element Yagi arrays to 12 wavelength rhombic antennas.

Television happened for me at an infectious age. A paper route helped me maintain a library of that era's **Radio-Electronics** and a host of other valuable trade magazines that were documenting the fast changing world of television technology. Summer odd jobs and caddying at the golf course enabled me to buy aluminum tubing, wire, electronics parts and bargain-basement-priced 630 chassis. In later years I would sometimes wish that I had been born "only five or ten years sooner" so that I would have been old enough by 1950 to have really been in a position to participate fully in the television revolution. "But alas" I would say to myself "that's it for the television revolution. Now that it's established nothing will come along to change it 'that much' so I'll just have to find my nitch someplace else."

And so it was until 1975 when I discovered a whole new television revolution just getting underway—satellite TV transmission and reception. And I have been tracking it, playing an active part in it and enjoying it ever since.

## Forget everything you know

If you are in the television business to make a living, you probably think you know all there is to know (or need to know) about reception techniques and equipment. You've tracked down ghosts and explained away weather-caused co-channel interference. You've doped out MATV systems and traced bad components. You've been stuck with an inventory full of "brand name" parts that overnight went off the market, and you own every Sams *Photofact* that they ever printed. Forget it all!

First, let me tell you a bit about the TV reception in my present home, some 20 miles outside of Oklahoma City. We have the usual three major networks as well as PBS (Public Broadcasting System). And like a good majority of the United States, that is all we have (or *had* until the fall of 1977).

In August 1977 I placed some 1 × 2 stakes in our sidelawn and backhoed enough clay to let me refill the holes with a few pieces of properly formed steel and around 4 yards of concrete. Then, in September 1977, I brought in a crew of friends and this funny-looking, 3000-lb., all-steel saucer-shaped apparatus, and in about eight hours we had the saucer mounted on a set of steel posts. (See Fig. 1.) The saucer pointed more or less south of us and up into the sky.

The same evening I sat down with a special receiver and watched the evening news live from Vancouver, British Columbia; a baseball game from Atlanta, GA; and a movie via some-



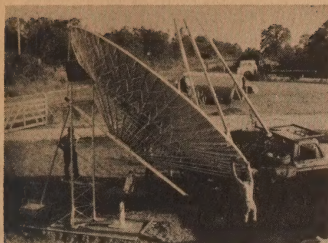


FIG. 1—SATELLITE RECEIVING ANTENNA as it is being installed on steel mounting posts.

thing called HBO (Home Box Office).

My home is located just 18 airline miles from our local network and PBS stations, and I had always been able to receive the best-looking TV pictures this side of a network monitor, up until that fabled September 1977 evening. Until you have had a high-quality color monitor plugged directly into the video output of a satellite TV receiver and observed 54-dB signal-to-noise-ratio video produced by people who really care about how good it looks when it leaves their studio, you simply have not seen how good NTSC color reception can really be!

Let me digress a bit and explain what satellite television is all about, how it works and why it works the way it does.

#### How it began

The first man-made satellite was Russia's SPUTNIK (1) in the fall of 1957. It shook a lot of people up as you may recall. The idea of a ton or so of steel and electronics going around and around the world and crossing our country beeping in Morse code and doing who knows what else spurred the U.S. into the space race. We responded by launching a U.S. Airforce satellite named SCORE in December 1958, and to one-up the Russians, we added a prerecorded message from the President of the United States who welcomed in the American space age and the Christmas season.

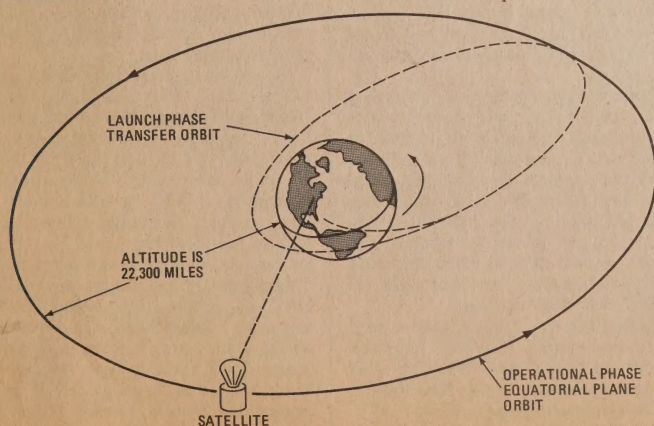


FIG. 2—GEOSYNCHRONOUS ORBIT is achieved by launching satellite into a highly elliptical orbit that is followed by a transfer to an equatorial plane orbit. Satellite's position over equator is typically maintained to  $\pm 0.1$  degree.

TABLE 1—INTELSAT GEOSTATIONARY satellites operating in the 3.7- to 4.2-GHz down-link frequency band are clustered in three separate areas.

Longitude (west)	Name	Year Launched	Service Status
1°	I-IV-F7	1973	Secondary
4°	I-IV-F2	1971	Reserve
19.5°	I-IVA-F4	1977	Reserve
24.5°	I-IVA-F1	1975	Primary
29.5°	I-IVA-F2	1976	Reserve
34.5°	I-IV-F3	1971	Secondary
181°	I-IV-F4	1972	Reserve
186°	I-IV-F8	1974	Primary
297°	I-IVA-F3	1978	Primary
298.6°	I-IV-F1	1975	Primary
300°	I-IV-F5	1972	Reserve
300°	I-IV-F6	1978	Reserve

SPUTNIK, SCORE and all the satellites that followed them through 1963 had one common fault. They were launched into a "low orbit" and (with reference to a point on earth) they were always moving. To receive messages from or transmit messages to these "low orbit birds" required that the stations working with the satellite know rather precisely its orbit path and the timing of that path, and then be prepared to track the satellite as it came over one horizon, moved in an arc through the sky and finally disappeared beyond the opposite horizon.

In 1963 space technology and rocket power progressed, and SYNCOM, designed and built by the Hughes Aircraft Corporation, was launched—the world's first geostationary (or geosynchronous) satellite. (A geostationary satellite has an orbit directly above the equator and an orbital velocity that matches the rotational velocity of the earth. (See Fig. 2.) In this way, the satellite appears to remain stationary in the sky with respect to a point on the earth.) SYNCOM was an experiment. It provided the capacity to relay either a *single* TV channel or 50 separate telephone conversations; from its orbit above the Equator between Africa

and South America, it interconnected North America and Europe with their first real-time (live) television transmissions. By 1965 the geostationary satellite looked like a winner, and 19 countries joined to form something called Intelsat, a consortium of nations that would fund the launching of a series of satellites.

#### The Intelsat world

With nearly 14 years to grow, the Intelsat system is relatively mature. Today, more than 100 nations belong to the system, which consists of 12 separate satellites located in three distinct "groups." Commercial Intelsat installations cost in the megabuck region, but amateur builders of backyard terminals have successfully tapped into the Intelsat circuit, using surplus-salvaged parabolic antennas as small as 8 feet in diameter and with investments well under \$500, as we'll discuss in some detail.

As mature as Intelsat is today, it is in a constant state of evolution. The present satellite series is generally of the so-called Number IV (or "4") class, indicating there have been three previous series. Table 1 lists where they are located; a sharp eye will spot the three "clusters" in operation: One is over the Equator in the Pacific Ocean; another over the Indian Ocean north of the Seychelles Islands; and a third between the tip of Africa and the tip of South America. Each location has as a minimum a "primary" and a "reserve" satellite, but heavy Atlantic and Indian Ocean traffic has resulted in additional satellites in these areas. In 1971 the Intelsat consortium agreed that identical-frequency satellites should be spaced over the equator in 4- to 5-degree increments. In this fashion the large parabolic ground-receiving antennas could intercept the desired satellite's signals without interference from adjacent-position satellites, even though both would be operating on the same frequency simultaneously. The present series IV satellites will begin to be replaced with a new, advanced family of satellites during 1979, the Intelsat V series. We'll look at these later on.



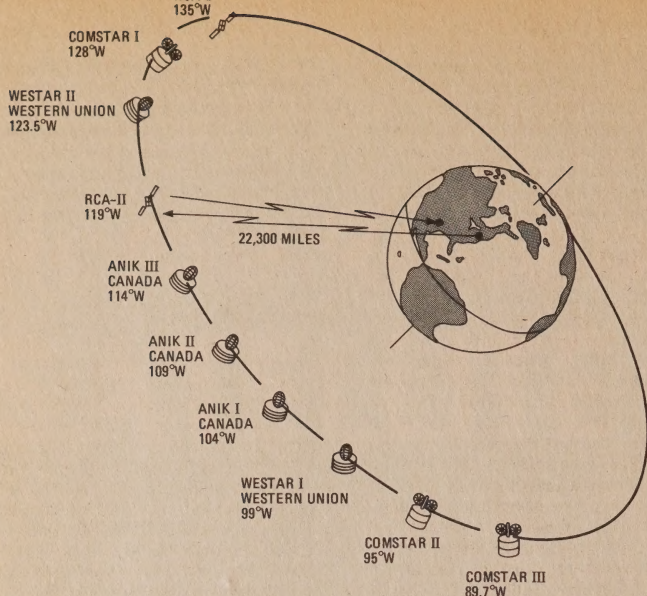


FIG. 3—DOMESTIC SATELLITE "parking" spots. Ten domestic satellites are currently active—3 Canadian and 7 U. S. A. A third WESTAR satellite should have been launched by the time you read this and a third SATCOM is due for launch between October and December of this year.

### Domestic satellites

As needed as the Intelsat-type satellites are, they cannot serve all the communications needs of all countries. Some nations, such as the U.S., Canada and Russia, have unique internal needs that in sheer message volume (or circuits required), far outstrip Intelsat's services. For example, in the Atlantic Intelsat cluster five separate satellites have a total flat-out capacity of 100 separate "channels" or transponders. A single transponder can provide (typically) up to 900 voice or message circuits, or one TV channel circuit. Obviously, not all these circuits are used full time, so satellite communications planners take advantage of what are called "peak load times." They attempt to have enough circuits available to handle peak or maximum traffic-time loads. In the long haul, the average number of circuits in use would be somewhat less than 50% of the total capacity available.

Some smaller nations, such as Nigeria, Sudan, Uganda, etc., lease one or more transponder/channels full time from Intelsat to provide ground-to-satellite-to-ground communications for circuits wholly within their own countries (except for the satellite link). Other countries such as Spain, lease full-time circuits to maintain ground-to-satellite-to-ground communications with distant outposts of their nation, for example, television, telephone and data circuits with the Canary Islands.

In 1970-1971 individual countries with projected satellite circuit needs for exceeding Intelsat's capability persuaded other Intelsat nations to allow some portions of the equatorial orbit belt to be

reserved for non-Intelsat geostationary satellites, or for domestic satellites. In the interim so-called Domestic Satellite Systems have been activated for Indonesia, Canada, Russia and the U.S. although actually the Russian system was first made operational back in 1965.

In North America the orbit parking region from 70 degrees west longitude (a point due south of New England) to around 135 degrees west (roughly due south of the Alaskan peninsula) is reserved for North American domestic satellites. (See Fig. 3.) Canada was the first to launch a domestic satellite into this region (ANIK I in 1972); and in seven years, 10 other Canadian or U.S. domestic satellites have joined ANIK I. An additional pair of U.S. domestic satellites will join the crowd before 1979 is over. There are 13 satellites in all, and all are parked between 70 degrees west and 135 degrees west.

On a transponder or channel-capacity basis, the North American satellites have the full-load capability to provide as many as 228 separate TV channels, or more than 200,000 telephone voice channels simultaneously—more than twice that available on the Intelsat system. With all that capacity available, you might suspect there is some extremely interesting, perhaps even downright enticing, "television" up there.

Indeed there is. There's a lot of good watching—more than 40 channels worth—to be had from those U.S. and Canadian domestic birds. Next month, we'll take you channel-by-channel, bird-by-bird as we scan programming available to TV viewers in other locations throughout North America.

R-E

## Part 2—The conclusion of a story on domestic satellite communications and its use in distributing TV programs

LAST MONTH WE GOT A LOOK AT EARTH satellites and how they are used in domestic and world-wide communications. Now we'll conclude with a look at the "birds" that carry TV programming of interest.

### 40-plus TV channels

Imagine you're sitting in your living room on a Sunday afternoon trying to decide what you want to watch. On local TV (or "terrestrial" as we'll call it from this point onward) there are a couple of network-selected regional professional football games, an old movie and a PBS program on how to prepare fall bulbs for planting. The two football games don't include any team you are really interested in, so, let's see what's on the satellites.

We'll start on the eastern edge of the active U.S./Canadian orbit belt with the WESTAR I at 99 degrees west:

Transponder 1 has a pro football game being relayed via satellite to who knows where; Transponders 2, 6 and 10 also feature football games, none of which are on terrestrial TV. Transponders 8, 9 and 11 present three separate PBS programs, one matching the local PBS channel. Transponder 12 is showing a professional soccer game originating in Minneapolis and relayed to Los Angeles. Next, ANIK III, the prime Canadian satellite, is stationed at 114 degrees. On Transponder 4 the CBC is running a "pre-network feed" for a program to be viewed on terrestrial TV later that evening in Canada. Transponder 8 shows a French language movie. Transponder 10 features a Canadian Football League football game, while Transponder 12 is showing a hockey game from Vancouver.

Moving on to RCA SATCOM F2 (at 119 degrees) Transponders 4, 10, 16 and 20 are showing more pro football games. One of these games is being shown on your local NBC affiliate; the other three are not available locally. On Transponder 8, there is an NBC network prefeed of that evening's Walt Disney program, beamed from Los Angeles to New York for network viewing several hours later. Transponder 18 has another prefeed for NBC; this one is a news report for the next day's "Today Show". On Transponder 22 a golf match is being relayed live from a South Carolina locale where it is being transmitted to major-market independent TV stations. Finally, Transponder 23 is carrying a special program presented by the Alaskan Native's Federation, being relayed via satellite to ap-



proximately 50 Alaskan "Bush Terminal" sites.

Our next stop is WESTAR II at 123.5 degrees west. Between WESTAR I and SATCOM II we've already run into eight professional football games. Eleven will be played that afternoon so we are not surprised to see engineers, technicians and announcers preparing for one more on transponder 3. Transponder 1 carries New York City's WOR-TV, (a highly rated independent station) which is being fed to cable systems, and is showing an old black-and-white Bogart film. On Transponder 4 Chicago's station WGN is showing *Star Trek* to cable systems. Transponder 7 shows a bullfight, direct from Mexico City's station XEW-TV. Transponder 7 carries an average of 12 hours of Spanish language programming per day, much of which is transmitted directly from Mexico City to a handful of U.S. Spanish language TV stations in Miami, San Antonio and Los Angeles. Way up on Transponder 12 station KTTV in Los Angeles, another independent station being fed to cable systems nationwide, is wrapping up the Dodgers' baseball season. Since this station televises around 100 live Dodger games each year, this broadcast of a Dodger game fits its format.

There's still "nothing to watch," so you head for "the big one," RCA's SATCOM F1 (at 135 degrees west). You run through one of the three ATT/GT&E "telephone company" birds, COMSTAR I, at 128 degrees west. Normally, they don't have much video on them but you check anyway. There on Transponder 14 are a couple of people talking. It seems to be one-half of a conversation. Up on Transponder 18 you find the other half: a group of scientists in Honolulu are talking with politicians in San Juan.

You're not interested, so you now move the antenna round the last notch to SATCOM F1. Surely here you will find something interesting to watch. After all, there are 20 separate almost full time video channels on F1!

On Transponder 1 station KTVU from San Francisco, another independent station, is showing a movie. Transponder 2 carries PTL, a 24-hour-per-day religious-based family entertainment service. Transponder 3 is showing Chicago's WGN broadcast of *Star Trek* again. On Transponder 5 you find "Nickelodeon," a 13-hour-per-day Children's Television Network created by Warner (Brothers) Cable. Transponder 6 carries Atlanta's "Super Station" WTCC, with wrestling. On Transponder 7 "ESP," a New England regional service, is showing playbacks of the area's college football games. Then on Transponder 8 you tune into CBN (Christian Broadcasting Network) the original 24-hour-per-day, satellite-transmitted religious-family channel.

Transponder 9 gives you Knicks basketball game direct from Madison Square Garden (there are more than 1000 hours of Madison Square Garden events on this

transponder per year). During the week and in the daytime, Transponder 9 televises U.S. House of Representatives sessions live from Washington, which also totals about 1000 hours per year.

On Transponder 10 you find the West Coast feed for "Showtime," a 12-hour-per-day movie and entertainment service; they are running a current children's (G-rated) hit movie. Tuning to Transponder 11 you find Warner's "Star Channel," a 14-hour-per-day movie and entertainment service, showing a Tom Jones nightclub act from Las Vegas.

Transponder 12 gives you "Showtime's" East Coast channel and a Burt Reynolds movie. One nice thing about having an East and West Coast feed from SHOWTIME (and HBO) is that if you don't have the time to sit down and watch Burt Reynolds now you can come back in three hours and catch it on the West Coast channel at that time. Transponder 13 is running some engineering equipment tests. Transponder 14 also is showing the 24-hour-per-day religious channels—KTBN or Trinity Broadcasting. Only this channel, unlike PTL (Transponder 2) or CBN (Transponder 8), is a regular broadcast TV signal that happens to be sent out via satellite. (CBN and PTTL are special feeds created just for the satellite) On Transponder 16 you find, "Fanfare," a southwestern U.S. regional pay cable service specializing in late-release movies, nightclub and stage acts, and regional sports. Transponder 18 shows some digitally transmitted news from Reuters, on which, with a special receiver adapter, you can watch the latest world news. Transponder 20 is running a movie epic on oil exploration. Transponder 22 has the West Coast feed for HBO (Home Box Office), and as you tune in they are previewing the day's movie and special fare. Transponder 23 has the HBO family-program service called "Take Two"; and a recently released Walt Disney movie. Finally, in the last transponder position, HBO's East-Coast feed service gives you the movie you wanted to watch. Decisions, decisions: Should you watch the movie now or catch it later on West Coast Transponder 22?

From Canadian hockey live from Vancouver to a bullfight telecast live from Mexico City, you have a choice of 11 professional football games, a motorcycle race from Houston or a soccer match from Minneapolis. These broadcasts are shown with such clarity and resolution that you almost feel compelled to reach out and touch the screen. That's what

satellite TV means to those equipped to receive it.

Are people actually watching all these programs? They sure are, and with their own backyard receiving systems.

They all must be millionaires, you might think. To be sure, a few had to be able to afford the prices being charged for "cable television grade receive terminals" back in 1977 or even early 1978. But let's back up a few steps again and take a look at some of the satellite specifications.

## Microwave in the sky

A satellite is a combination of microwave electronics, solar-powered electronics and rocketry. Stripped of all of its mind-boggling exotic details, a satellite is nothing more than an unattended relay station. It has one set of antennas to receive the transmissions originating on earth (called uplink signals), and another set of antennas to retransmit those signals back to earth (called downlink signals). The uplink signals are between 5.9 GHz and 6.4 GHz (5900 MHz to 6400 MHz), and the downlink signals are between 3.7 GHz and 4.2 GHz (3700 MHz and 4200 MHz).

The uplink and downlink frequencies divided into (typically) 40-MHz-wide channels; and since the up and down frequency bands are 500 MHz wide, there is room for 12.5 such channels both up and down. This results in a maximum capacity of twelve 40-MHz-wide channels, plus some room for ground-to-satellite command signals, satellite-to-ground acknowledgment signals, and a couple of "beacons" to help ground control measure exactly where in space the satellite is located at any given moment. (See Fig. 4.) There can be more than 12 channels on a single satellite, however, and we'll see why that's possible in a later article.

The electronics inside most of today's satellites is fairly similar in design up to the output stages and the transmitting antennas. The uplink signals (between 5.9 GHz and 6.4 GHz) are received via fairly wide-beam "sculptured" antennas that cover all the service area fairly efficiently. Being directional antennas, they have a pattern, and in satellites the center of the antenna pattern is called the "boresight point." The boresight point on the receive antenna is where maximum gain occurs, as well as on the downlink transmitting antenna. All received signals are processed by a broadband (5.9–6.4 GHz) front end. The signals are amplified and fed into a converter stage that translates

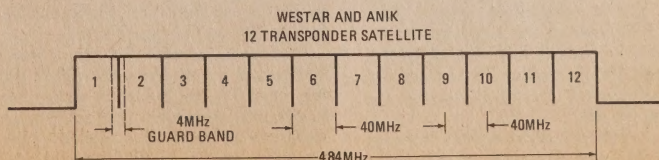


FIG 4—THE DOWNLINK BAND is 500 MHz wide from 3.7 to 4.2 GHz and is divided into 12 channels. Each channel is 40 MHz wide.



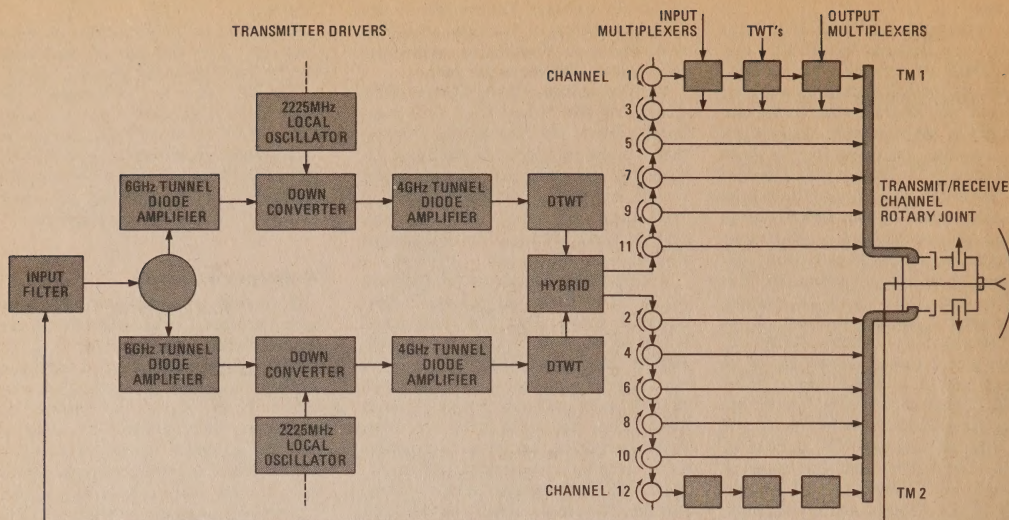


FIG. 5—12 CHANNEL SATELLITE designed by Hughes Aircraft.

their incoming frequency down directly to the appropriate area in the 3.7- to 4.2-GHz range.

Figure 5 is a block diagram of a typical 12-transponder satellite, in this case, the ANIK series. Note that the input side is redundant; this is a security measure in case something in this broadband circuit area should fail prematurely. Once the signals have been translated down to the 4-GHz range, they are fed into the appropriate output-amplifier stages; individual TWT (Traveling Wave Tube) output-amplifier stages are included for each transponder. The peak power at this point is 5 watts (+7 dBw, or decibels above 1 watt) and from there the 5 watts are coupled into the appropriate downlink transmit antennas. The transmit antennas have gain (with reference to a dipole or isotropic source) and the gain added by the directional transmit antenna measured in dB's is added to the power-output level of the TWT amplifier. This results in an effective radiated power (EIRP) for the downlink system. At boresight on the transmit antenna, the power generated is in the +34-dBw to +37-dBw range; this varies slightly from satellite to satellite.

The ground-to-satellite signal path (in the 6-GHz range) requires substantial transmitter power (i.e., 1 kW to 3 kW) plus large antenna gains (50 dB to 60 dB) to saturate the input of the satellite with high-quality (noise-free) signals. Like any relay station, the signal quality returning to earth is only as good as that initially transmitted to the satellite. On the uplink path, free space loss approximates 198 dB.

Our primary interest is in the downlink path since that is where we can participate. Figure 6 shows how the ANIK satellite views Canada:

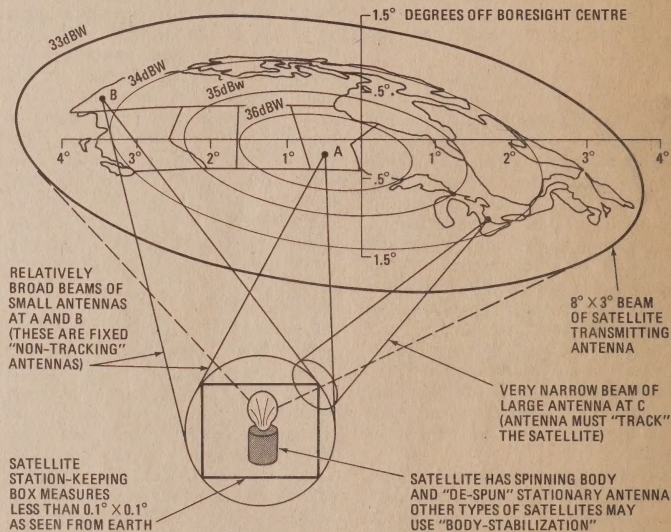


FIG. 6—TYPICAL COVERAGE of the earth's surface by a satellite. Two different approaches to receiving antennas are shown. Small antennas with a broad beam can be non-tracking while large antennas with a narrow beam must track the satellite.

### TVRO terminals

TVRO (TeleVision Receive-Only) terminals really came into being when satellite relay service was inaugurated for cable TV companies. Since September 1975 their development has followed closely the established criteria for the big (and expensive) Intelsat stations.

When the first cable TV use of satellites started the present gold rush in the sky, the FCC had no ready system for handling the explosion. Because Intelsat stations were more often than not both reception and transmission systems, they naturally required FCC licenses. Domestic terminals that were first installed by

RCA, Western Union and (in Canada) by Telesat were both transmit and receive terminals. RCA, for instance, built ground-station terminals near major metropolitan centers and used terrestrial microwaves to link into and out of these centers. The New York City area is served from a location near Sussex, NJ, called Vernon Valley. This site (close to two other major uplink and downlink control sites) is the "first north-south valley location west of New York City where there is terrain shielding" from terrestrial microwave emissions.

This is important because the downlink frequency band in use (3.7 GHz to 4.2



GHz) is a shared band, that is, it is also used as the heavy microwave trunk route for the Bell Telephone Company (and other phone systems) throughout the U.S. Because the telephone company microwave circuits criss cross the country in the same frequency band as the downlink signals from the satellites, there exists a potential for interference. Fortunately, because of the highly directional characteristics of the parabolic antennas used in satellite reception (and the point-to-point "thin-line path" design of terrestrial telephone circuits) the two can operate closely without interference. What interference there is results from transmissions from the terrestrial circuits to the satellite-receive terminals since the latter do not transmit. (My own terminal is only 2.4 miles from a major Bell Company relay site, but we have never experienced any interference at our receiving TVRO.)

This does indicate however that occasionally a nearby terrestrial microwave transmitter, located either very close to you and to the side or out in front of you (i.e., on a line towards your satellite heading), could cause some interference with satellite reception. We'll look at solutions to this problem in a later article.

One of the manageable things about the satellite-to-earth system is its high degree of signal-level predictability. Between the excellent station keeping by the "flight engineers" and the well-known parameters of space loss between the satellite and earth, engineers with calculators or enthusiasts with TRS-80 computers can determine within 0.1 dB the type of signal level that can be expected at a given location. Adjusting to 0.1-dB signal-level steps is part of adjusting to satellite technology.

The satellite's signal is contained within a 36-MHz-wide frequency bandwidth. The video signal is frequency-modulated (FM) and the audio signal is also FM, being transmitted as a subcarrier signal at either 6.8 MHz or 6.2 MHz. Because this is an FM/FM system, several important factors must be considered that are not part of normal AM (terrestrial TV) transmission. The foremost factor is called "the FM threshold." Let's simplify what that is:

1. When an FM signal (on an FM set, a two-meter amateur radio, etc.) reaches "full quieting," all background noise is gone.
2. As long as the signal stays above the "threshold of noise," you have no way of judging (without some complicated meter measurement) how close you are to the noise since in "full quieting" there is no noise.
3. The signal may be far above quieting (into heavy limiting) or it may be simply right on the ragged edge (on the plus side) of noise; it all sounds the same.
4. However, when you fall out of full

quieting (that is, the signal level slips down in level and there is no limiting action) noise appears quite suddenly and often very dramatically.

This indicates that if the frequency-modulated satellite video signal could be maintained just above the noise threshold and if the satellite signal was very stable, you could get by with a "low-margin" (for fading) receive system that would to all normal eyeball testing give the same apparent picture quality as a signal that is many many dB stronger than full quieting. When you include in your calculations a parameter called the FM advantage (along with the other parameters of this particular system), a noise-free picture occurs when there is a 48-dB signal-to-noise ratio, as measured at the base-band video signal. FM advantage derived from this type of service, with normal receivers, is around 37 dB (give or take a few tenths of dB's). If you subtract 37 dB (the FM advantage) from the noise free video signal-to-noise ratio (48 dB) this gives you the type of 4-GHz-range carrier-to-noise ratio your receiver must attain: in this case,  $48 - 37 = 11$  dB. Some fine tuning can be done with these values, but for now they are close enough.

When you go through all the system's mathematical components (satellite EIRP minus free-space loss minus receiver-noise value plus antenna gain) for 48 dB video signal-to-noise pictures, you need a 10-foot parabolic dish antenna with a 2.6-dB noise figure signal preamplifier, also called a low-noise amplifier (LNA). This is if you are within a 36-dBW contour and use a receiver with an adjusted IF bandwidth of 27 MHz.

Let's leave you with this bit of reassurance. If you sat down with an order form from established, reputable manufacturers selling hardware to the CATV (etc.) commercial users and bought everything you need for this type of reception already assembled (you would do the actual installation), you could buy everything necessary for 48-dB video signal-to-noise-ratio reception for less than \$5500. And that includes a 24-channel tuneable receiver.

While a far cry from the \$100,000 early turnkey cable systems of 1975, it may still be too rich for your blood. So, let's add this postscript: If you built your own antenna and LNA, and assembled your own receiver from prewired and tested modules, it would cost about \$3000. Still too much? Here's the bottom line for this month: A California hobbyist assembled his own system for under \$1500, using lots of ingenuity and a good knowledge of surplus equipment. And a fellow in Sheffield, England, built his private terminal for under \$1000. We'll dig into all this with some enthusiasm in a future article.

R-E

## *Part 3—This month we'll see where home satellites stand legally and then take a good look at the technical requirements and how they are met.*

IN THE AUGUST AND SEPTEMBER, 1979 issues of **Radio-Electronics**, we learned that, through a network of largely non-affiliated geo-stationary communication satellites, multiple channel television is now available to virtually any point on the globe. Satellite television, using geo-stationary satellites, rises above terrestrial television in many ways. It is virtually immune to interference, does not suffer from lower atmosphere weather changes, and is of a technical quality that can only be approached (but not exceeded) by the ground-based microwave networks that link the cities of a nation together in a communications grid.

Now we are going to learn how this marvel functions, and how persons with some mechanical skills and ambition can put it to work for themselves.

### **The legal side**

There are as many myths around relating to the legalities of building your own satellite terminal and intercepting satellite television broadcasts as there are myths concerning equipment. The bottom line is that *you can do it*, although there are FCC rules, regulations, and policies that restrict the nature of what you can do legally.

The FCC is responsible for governing two different types of transmissions: public and private. Public transmissions include the radio broadcasting you listen to and the television broadcasting you watch. Any transmissions intended for the public at large are public broadcasts. In the United States no license is required for reception of such signals. Private broadcasts are another matter.

A private transmission would include public safety transmissions (intended only for personnel operating as a part of the licensed system), mobile telephone transmissions, and the many forms of common carrier transmissions. In other words, if the transmission is *not* intended for the public at large but for one or more specific addressees, it is private. The FCC



<sup>2</sup> A complete textbook on building your own 16 foot aperture TVRO antenna using readily available hardware store supplies is available from PARAFRAME R & D, P.O. Box 423, Monee, Illinois 60449 (312-534-7435). That antenna has been developed primarily for duplication by private terminal enthusiasts and the manual includes step-by-step construction details including full parts sourcing.



directly into a low noise amplifier (or LNA, as it is known in the trade). That is simply a signal booster, not unlike the antenna mounting signal boosters used for fringe area terrestrial TV. However that is where all similarities cease. The LNA is rated by its gain and by the noise factor (*i.e.* noise figure). Gain is important, but that is secondary to the noise figure of the unit. To achieve the kind of noise figures required to produce high quality television pictures we have to push the science of transistor technology to its very uppermost limits. The latest thing in low noise transistors for the 4 GHz frequency range are GaAs-FETs: Gallium Arsenide Field Effect Transistors. The latest of these devices are capable of creating noise figures in the 1.2 dB region. However there is a price for such low noise at 4 GHz: money. The transistors available for this application are in short supply (although it is improving rapidly) and that keeps the price up. A per-transistor-price of \$200-\$300 is not uncommon and a pair in that range are typically required in commercial LNA units.

There is another way to go here; to lower the costs, the system designer can trade antenna size for LNA noise figure. By using less expensive front end transistors and a slightly larger antenna, the home builder can shave large dollar numbers from the terminal cost as we shall see.

In a commercial installation, the LNA is connected to the receiver through a length of low loss coaxial cable. If you are into cable, you should suspect that at 4 GHz regular coaxial cable is a disaster; RG8, 11, or other cables (including even the CATV type aluminum sheathed cable) have very high losses at that frequency. Therefore you graduate to more expensive cables with larger diameters and lower loss. The most commonly employed cable for this application is the *Helix* or spiral-air insulated line. Losses in 100 feet are in the 4-6 dB range at 4 GHz and that can usually be tolerated.

The receiver can be called a demodulator since it actually takes the 4 GHz input signal and through a series of steps translates the RF signal down to baseband video and audio. Receivers in the commercial area are available in either single channel or tuneable formats.

The LNA must be powered and the most common power source is a DC supply in the 12-18 volt region. Normally a power line carrying that operating voltage is run from the inside location to the antenna where the LNA mounts. The current requirements are minimal (150-250 mA being typical) although voltage transients are a problem since the GaAs-FET's tend to be easily destroyed by spikes. Therefore many LNA supplies are Nicad cells constantly under trickle charge with the LNA connected to the battery bank that acts as a

"sump" for primary line voltage transients.

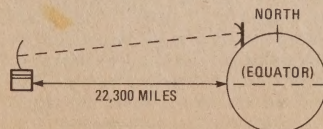
Because we cannot convert the FM/FM format to a standard TV receiver IF and then to video/audio, the output of the satellite video receiver is baseband audio and video. To view this signal requires a separate box or series of boxes. For the highest quality local viewing most systems have one or more studio-type color video monitors. Such monitors are expensive, but with extremely high signal to noise video coming out of the satellite receiver (50-55 dB signal to noise is the range we are dealing with) the end result (the picture) is enhanced by this approach. That's fine for on-site viewing, but not practical for multiple viewing locations. Therefore most often the baseband video/audio signals are looped to a TV RF modulator operating on some specified TV channel. Modulators come in all shapes, sizes, and price ranges, running the gamut from single transistor oscillators to complex mini-broadcast stations with separate audio and video modulation controls, aural to visual carrier ratio controls, peak white limiting, and a host of other professional features. Once we've fed the satellite baseband signals to a TV RF modulator the signal may be carried on through standard 75 ohm coaxial cable (as found in MATV, CATV and home cabling projects) to an infinite number of standard TV receivers.

### The parabolic antenna

The antenna does two important things for the system:

1. It provides the necessary signal gain to produce a 4 GHz signal level of sufficient intensity to create an interference-free picture, and,
2. It provides a way to discriminate (separate) between the desired signal and others operating in the same frequency range that are not desired at that moment.

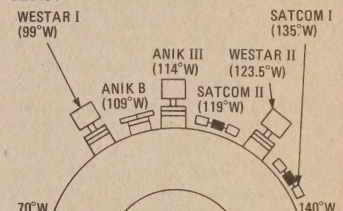
If you could stand off to the side of the earth, as depicted in Fig. 2, and look at a cross section of the earth plus the geostationary satellite belt, you would notice that for locations north of the equator the satellite antenna has to look "downhill" to see the satellite hovering above the equator. For a satellite terminal directly on the equator, the satellite is overhead. For locations north of the equator, the satellite is progressively lower and lower to



**FIG. 2—THE GEOMETRY of the earth-space system.** The geostationary satellite is positioned directly above the equator approximately 22,300 miles. The satellite is maintained in a "station-keeping" box approximately 70 miles on a side by earth controllers.

our southern horizon as we progress north. That "tilting" of the satellite receiver antenna is measured in terms of inclination. An antenna pointing exactly at the horizon would have a 0 degree inclination while an antenna pointing straight up would have a 90 degree inclination. For most of North America, the inclination is between 50 degrees down to eventually 0 degrees at the 80th north parallel. By placing a protractor (angle finder) parallel to the flat back surface of the dish and measuring the inclination (or elevation angle as it is also known) you can adjust the angle to match the desired angle. A computer chart that spells out the elevation angle, azimuth angle (left and right), and distance to all visible geostationary satellites from your location is available.<sup>3</sup>

Rather than standing off to the side of the earth, if you moved to a point directly above the north pole and looked down at the earth and the circular orbit belt surrounding the earth you'd get a view similar to Fig. 3, which shows only the six television carrying satellites presently in service for North American domestic relay. By international agreement the orbit belt from 70 degrees west to 140 degrees west is set aside for North American domestic relay satellites. Also by international agreement all such satellites are required to maintain a 4 degree spacing between themselves, as a minimum. For example, SATCOM II is located at 119 degrees west while WESTAR II is located 4.5 degrees further west at 123.5.



**FIG. 3—THE SATELLITE geostationary belt as seen from a position directly above the north pole of the earth.** U.S. and Canadian "orbit belt" extends from approximately 70 degrees west to 140 degrees west longitude. From your location a satellite due-south of you will appear highest "in the sky" while satellites east or west of that point will gradually be closer and closer to the "horizon" as their longitude differs more from your own.

<sup>3</sup> A highly useful computer derived chart that locates every geo-stationary satellite location that is within "line of sight" of your location is available. Enclose your geographic coordinates (longitude and latitude with degrees and minutes) and order from TPI, Suite 108, 4209 NW 23rd, Oklahoma City, Ok. 73107.



Now, years ago the FCC was a party to an international set of technical standards that specified that domestic satellite earth terminals had to use receive antennas "no less than 9 meters in size . . ." a whopping nearly 30 foot aperture. Naturally, for as long as that rule was on the books earth terminals cost a bundle, \$100,000 being typical.

In early 1976, I conducted tests to determine just what type of service might be practical with smaller antennas and determined that antennas down to at least 4.5 meters (15 feet aperture) provided adequate service and that such antennas were not bothered from interference created when two adjacent-in-orbit position satellites were operating at the same time on the same transponder channel. Those tests were refined and submitted to the FCC in the form of a Petition for Rule Change and in late 1976 the FCC changed its rules and allowed antennas smaller than 9 meters (down to 4.5 meters) to be licensed for satellite receive terminal purposes.

There is, however, a substantial difference between a commercial terminal and a private (non-commercial) terminal. It happens that the FCC, in granting licenses for commercial terminals insists that these terminals maintain an "excess signal margin" of nearly 3 dB. What is an excess signal margin? The FCC says that when you design a receive terminal you will marry together the gain of the antenna, the known or predicted signal contour of the satellite being licensed for, the noise figure (and gain) of the LNA, and the receiver parameters to compute what your ultimate signal-to-noise figure at baseband video will be. As an applicant for the service you submit those calculations to the FCC as part of your license application. The rules state that if your calculations show the "threshold of noise" to be at the 48 dB signal-to-noise point (that is where it typically falls) then your terminal must have approximately 3 dB *more signal* than is required to attain the 48 dB ratio as a safety margin. It turns out that the 3 dB "excess signal margin" can be very expensive.

We've alluded to "signal contours" from the satellite several times so far. What happens is this: The output power is 5 watts per transponder channel. That output power is coupled into a directional antenna on the satellite and the directional antenna has lobe characteristics, like any other terrestrial directional antenna. Dead in the center of the pattern, where maximum gain occurs, is called "boresight." Off boresight the gain of the transmit antenna falls off and therefore the signal level on the ground becomes lower. Refer to Fig. 4 which shows a typical antenna EIRP (Effective Isotropic Radiated Power) contour pattern from an operating satellite. The strongest signal levels are found within the 36 dB portion of the coverage, while lower sig-

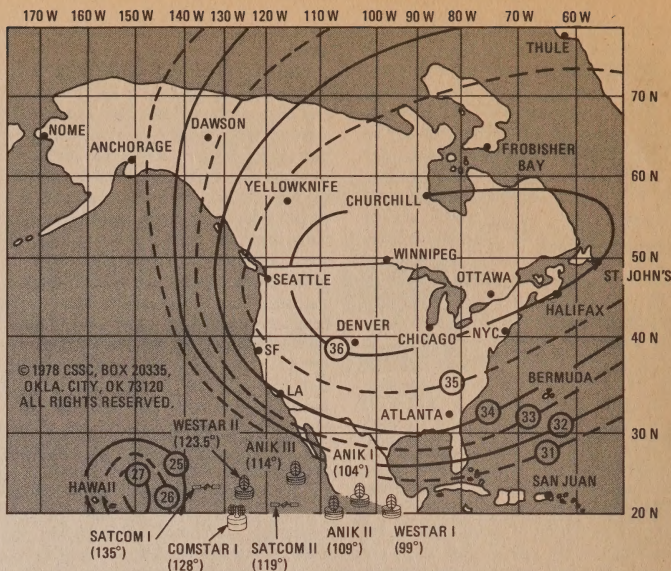


FIG. 4—SIGNAL LEVEL CONTOUR MAPS are called EIRP Contours. The output power of the satellite transponder (typically 5 watts) is converted to decibels above one watt (i.e., +7dBW) and is added to the gain of the transmitting antenna. If the antenna gain is 29 dB at boresight (center of the pattern) the radiated power becomes 7 + 29 or 36 dB EIRP.

nal levels prevail in the 35,34, etc. contour circles or ellipses. Sets of those maps are available for the primary domestic satellites in operation.<sup>4</sup>

#### The trade-offs

It turns out that there are several combinations to get the same signal to noise ratios. We speak of measuring signal to noise as a baseband measurement function. There are other ways to measure the system but that turns out to be the best system for repeatable apple and apple measurements, since we are dealing here with the final result of the whole system: the quality of the picture (and audio) as measured at the receive terminal.

Here are ways to increase the baseband signal to noise ratio at a location with a given signal contour (EIRP):

1. Make the antenna gain larger
2. Lower the noise figure of the LNA
3. Reduce the bandwidth of the receiver (by progressively sharpening up the IF bandwidth, ahead of the discriminator/demodulator)

Now if in a given (36 dBW EIRP) contour area calculations show that to license the terminal commercially you must employ a 4.5 meter (15 foot aperture) antenna plus a 150 degree Kelvin<sup>5</sup> LNA with a 30 MHz IF bandwidth, what would it take to produce not the FCC mandated 51 dB (48 plus 3) signal

to noise ratio but rather a more modest (for private use) 48.5 dB signal to noise?

The antenna could be reduced to 3.0 meters (10 feet), or the LNA could be replaced with a 300 degree Kelvin unit. Or, you could narrow the receiver IF to 15 MHz rather than 30 MHz, go to a ten foot aperture antenna and get by with a 180 degree Kelvin LNA.

The antenna gain and the LNA noise figure can be played back and forth directly without many side effects. Make the antenna larger, use a lesser quality LNA. Make the antenna smaller, use a better quality LNA. There are limits, of course (an 8 foot dish is about as small as you can go even in high EIRP areas and still expect a high quality signal.) The receiver IF trade-off is one of those areas that begs for additional well documented exploration. The transmitted bandwidth is nearly 36 MHz. However, most commercial receivers are employing 30 MHz IF bandwidths because they gain a bit in signal to noise that way without degrading the baseband video quality. Tests conducted by myself, and others, indicate that the 3 dB bandwidth points of the IF can be narrowed to 15 MHz on highly critical transmitted material, such as color bars, and the human eye cannot tell

<sup>5</sup> The science of noise figure measurement in the satellite equipment area is very sophisticated. LNA noise figures are measured by using the Kelvin (K) temperature scale with 0 degrees K being a no-noise source and higher K numbers indicating amplifiers with progressively higher noise figures. Certain benchmarks are: 1.0 dB noise figure is 75 degrees K, 1.5 dB noise figure is 120 degrees K, 2.0 dB noise figure is 170 degrees K, 2.5 dB noise figure is 225 degrees K, 3.0 dB noise figure is 290 degrees K and 4.0 dB noise figure is 435 degrees K.

<sup>4</sup> A set of 11 satellite EIRP maps is available covering SATCOM I (4 maps), SATCOM II (4 maps), WESTAR I and II and ANIK III (1 map each) from TPI, Suite 106, 4209 NW 23rd, Oklahoma City, Ok. 73107. Enclose payment with order.



that the picture quality has been degraded. Yes, on a waveform monitor you can begin to see some telltale signs of waveform distortion but to the eye that distortion is not yet apparent.

You can afford to engage in trade-offs because we are dealing with an extremely stable signal environment. In spite of the FCC's mandated 3 dB excess signal margin for commercial terminals (they say that is to protect the viewers connected to commercial terminals in case there are a series of simultaneous system degradations), numerous chart recorder tests indicate that worst case signal variations over a full year's term should amount to less than  $\pm 0.7$  dB of the nominal value. This suggests that once you attain performance that is above the noise threshold, you are "home free." This would be a good time to explain why you don't have the luxury of watching "slightly snowy pictures" with this service.

Noise in the picture disappears when the carrier level reaches a point where the receiver is into limiting. A 48 dB video (baseband) signal to noise actually indicates a carrier to noise (at 4 GHz) of perhaps 11 dB. In other words, if the carrier is 11 dB higher than the noise at 4 GHz you will have a 48 dB signal to noise ratio at baseband after demodulation. That incredible performance is made possible by something called the "FM Improvement Factor." In this service, with the bandwidths employed, it amounts to a healthy 37 dB (plus change). You can compute video signal to noise ratio by taking the FM improvement factor (call it 37 dB) and adding to that the carrier to noise ratio.

By now, you must be impatient to know (based upon your having spotted your own location in Fig. 4) just what type of equipment you might require at your own location to get 48 dB signal to noise ratio service. Some rough guidelines, subject to refinement, is shown in Table 1.

EIRP Contour	TABLE 1 Antenna Size	LNA Required
36 to 37	20 foot	600°K
	15 foot	300°K
	12 foot	200°K
	10 foot	120°K
	8 foot	100°K
34 to 36	20 foot	300°K
	15 foot	200°K
	12 foot	120°K
	10 foot	90°K
32 to 34	20 foot	200°K
	15 foot	120°K
	12 foot	90°K
30 to 32	20 foot	120°K
	15 foot	90°K

These are meant to be guideline numbers and are subject to some refinement since the system designer works with factors such as receiver IF bandwidth (30

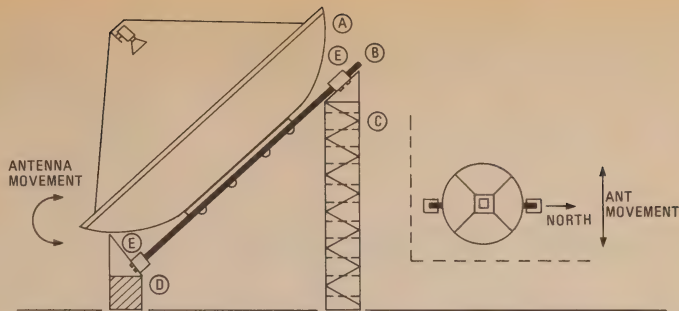


FIG. 5—POLAR MOUNT MECHANISM requires system that suspends the reflector surface (A) on an axle (B) suspended between two supports (C) (D). The axle "floats" in some type of thrust bearing collar (E) on both ends of the axle at each support. The taller of the two supports is the "north" end while the shorter is the "south" end. Supports (D) and (C) are spotted on the ground so that they fall precisely (within 0.1 degree true after magnetic correction) on a north-south line. The height of the shorter support is determined by the amount of azimuth play you wish built into the system. To be able to turn the surface from horizon to horizon requires a height at (E) at least equal to 50% of the diameter of the dish. The height of the taller support (C) is in turn determined by the height of the shorter support, and, your latitude. The farther north you are located, the taller the north-end support so that at the line-of-sight limit (80 degrees north latitude) the reflector surface sits virtually at right angles to the ground and points at your horizon.



ARTIST'S CONCEPT of the Satcom III satellite that will be launched in December 1979.

MHz is assumed in the above), antenna elevation angle (low angles start to become noisy) and so on.

If you miss the suggested goal by a small amount you can live with the result, which will be slightly noise marred pictures. Noise is more evident on a static picture (i.e. color bars, identification slide) than it is on a moving scene. In practice, if you are 1-4 dB below threshold you can sit and enjoy the picture and proudly show it off. It won't have that network-control-room look, but you'll be pleased with the results.

### The polar mount

Recall that our satellites are "stacked" horizontally along an imaginary line called the satellite belt. Within the control parameters, they are stationary inside of a 70-mile by 70-mile cube or box, which from our distant earth point means that they move so slightly that we won't notice the movement.

The geo-stationary belt reaches its maximum elevation for our own location

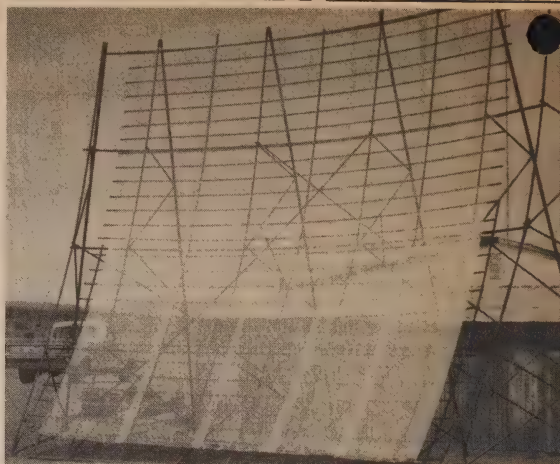
at a point due south. By using the charts available<sup>3</sup> we can determine how much elevation to adjust the antenna to for each of the locations where the satellites rest. This means that if you wish to move from one satellite to another, you would have to adjust the antenna elevation (angle of inclination) and also adjust the antenna's boresight (azimuth). These are two separate adjustments that interrelate. You might have the right boresight heading (azimuth) but if you have the incorrect elevation you won't see the satellite, and vice versa. There are many commercial antennas that use this type of mount adjustment system (called an Az-El as in azimuth over elevation) and for those installations where satellite changing occurs infrequently it is an acceptable system.

There is a better system, however, for frequent satellite change; see Fig. 5. The Polar Mount consists of a long axle on which the reflector surface is mounted, with the axle suspended in thrust bearings at each end. The thrust bearings or collars are in turn mounted on inclined surfaces, as shown with the south support stub quite short while the north support is fairly tall. The angle of the axle is your elevation angle for your particular location and, as you can see by dropping the short stub and/or raising the height of the north support, that angle can be fine-tuned for your particular latitude.

Now it happens, as a wonder of celestial mechanics, that if the two supports for the Polar Mount are fixed on the ground on a true north-by-south line and the inclination angle is adjusted for a true southerly heading so that, from that point onward, the Polar Mount will track across the geo-stationary orbit belt without additional adjustments to the elevation. That makes a very nice system for frequent satellite changes since the adjustments are now limited to one direction (left or right).



## Home Reception Using Backyard Satellite TV Receivers



SWAN SPHERICAL ANTENNA is effective in receiving satellite transmissions and can be built relatively inexpensively.

*Part 4—In this installment of a series, we will go into more technical details on receiver characteristics and specifications and will show how some satellite receivers have been built at comparatively low cost.*

ROBERT B. COOPER, JR.

IN PARTS ONE, TWO, AND THREE OF THIS multiple-part series (appearing in the August, September, and October 1979, issues of **Radio-Electronics**) we learned how the geo-stationary satellite system is designed, what it is intended to do and what a private individual, living someplace south of the 80th north parallel, north of Venezuela, and east-west between Bermuda and Hawaii can anticipate being able to receive with a private, backyard satellite television terminal. Satellite television is the next "generation" of television service in America and throughout wide areas of the world. Because of the mechanics of the service, it is virtually immune to interference and signal degradation, is not adversely affected by weather, and holds the potential to provide every home in North America with several hundred direct-access television channels!

### Receiving system

Having determined that the basic system consists of an antenna, a low-noise amplifier (LNA) and a receiver-demodulator, let's look at what it is that goes into each of these three major component modules to make up the operating system.

The antenna system has been adequately covered in previous portions of this series. Basically, in order to achieve

the kind of gain necessary (38 to 45 dBi) a parabolic reflector is the best antenna choice. This parabolic reflector has a single focal point where all of the energy intercepted by the reflective antenna surface is re-directed and focused. There are several acceptable members of the antenna family known as parabolics that can be pressed into this service; prime focus parabolics, Cassegrain parabolics and spherical parabolics are included. For as long as the (limited) supply holds out, surplus (as in no longer used in commercial or military service) parabolic (or "dish") antennas larger than 8 feet in diameter provide very economical "reflector surfaces" for most portions of North America. The exception to this is in New England where anything smaller than a twelve-foot reflector surface would be a mistake. Beyond that, one of the least expensive antenna surfaces for this service has been developed by a fellow in Arizona named Oliver Swan. Using aluminum window screening as a reflector surface, and stock square aluminum or steel tubing as reflector frame material, Swan has developed a spherical antenna system that can be constructed in virtually any size from 10 feet by 10 feet to 20 feet by 20 feet for as low as approximately \$500 for the ten-foot by ten-foot version. It is inevitable that some commercial firm will soon begin marketing antenna "kits" in this

area, perhaps copying the Swan developed spherical antenna and that from this will spring a whole new family of "backyard decorative pieces."

Because we are dealing with a low-power transmitter source (the typical satellite has a 5-watt peak power transmitter) and a fairly high loss between the "bird" and your receiving location (196 to 200 dB is typical at 4 GHz), not very much signal power arrives at your antenna. Fortunately, the signal received is very constant (variations of  $\pm 0.7$  dB over a full year are typical limits) and this allows us to design the system for peak performance and forget it rather than be concerned with wide-range AGC systems to cope with large signal fluctuations.

To make the most of the weak signal, we have to place a very high gain, and extremely low noise (figure) signal amplifier (or booster in TV terms) right at the antenna. Since the reflector surface on the parabolic is merely a focusing tool, the actual "pickup antenna" is really separate and distinct from the reflector. This receiving antenna, directed backwards away from the satellite and towards the focused energy coming from the reflector surface, is called a "focal point" or feed-point antenna.

The most efficient feed antenna is one that looks at the reflector surface in such a way that the "pattern" on the feed antenna is down 10 dB at the out-



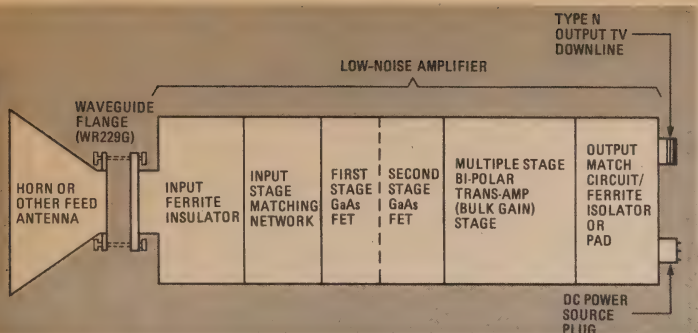


FIG. 1—MOST COMMERCIAL FEED-ANTENNA LOW NOISE AMPLIFIERS consist of a feed antenna (often a horn as shown for a prime-focus feed) which is equipped with a waveguide flange that bolts it directly to the input flange on the LNA (Low Noise Amplifier). The LNA has an input (ferrite) isolator both for frequency selectivity and as an impedance matching device for the first stage of the amplifier itself. The extremely low-noise amplifiers develop their superior operating characteristics because of extreme care taken in matching the first stage to the input source impedance and by carefully hand selecting the expensive GaAs-FET (Gallium Arsenide Field Effect) transistors. GaAs-FET devices are chosen for the first two stages. Once the noise figure is "established" by these two stages, less costly bipolar transistors are used in 3-4 additional stages for "bulk" gain. The output, to the low-loss downline coaxial cable, is through another ferrite isolator device or through a "loss pad" inserted to force an impedance match.

side edges of the reflector's surface area. A horn-feed antenna, properly designed, handles this function. Look closely at Fig. 1. Note that the horn-feed antenna is flanged or bolted directly to the low-noise amplifier itself; the energy from the horn feed-point antenna couples through the waveguide flange into the input circuit on the low-noise amplifier, a section that has a piece of ferrite (rod) in it as an isolator.

### Low-noise amplifiers

This commercial style low-noise amplifier is the state-of-the-art high-dollar approach to the low-noise amplification aspect of the system. There are less expensive ways to go as we shall see in subsequent portions of this series. The purpose of the ferrite isolator is primarily to insure that the input circuit to the first active (transistor) amplifier stage sees a constant impedance or load. This is done to insure that the transistor used in the first stage, a GaAs-FET (for Gallium Arsenide Field-Effect Transistor), is noise-figure matched at the 4 GHz operating frequency. Most of the high-dollar GaAs-FET's available for this service have two separate peak operating points; maximum gain does not coincide with best (i.e. lowest) noise-figure performance. In this case, gain is backed off in the first couple of stages as a trade off for lowest noise figure since noise generated in the early pre-amplifier stages is impossible to eliminate later on in the system.

Most of the commercial LNA units employ a pair of ultra-low-noise GaAs-FET's in the first two stages, and then follow that up with between three and five less expensive (typically bipolar as opposed to GaAs-FET) amplifier stages. Once the noise figure for the LNA is es-

tablished by the first couple of stages, less expensive (and higher noise figure) bipolar stages can make up the remainder of the LNA system gain required.

Noise figure is measured in both dB and by the Kelvin noise temperature scale. Most of the commercial data sheets will specify Kelvin temperature only and most commercial installations are using amplifiers with 120-degree Kelvin (or 1.5 dB noise figure) specs.

State-of-the-art has been catching on quickly in this field; in late 1976 the price for a 120-degree Kelvin LNA was in the \$3,500 region. By late 1978 you could find the same amplifier for around \$1,800. Today the price is down in the \$1,000 region and many expect it to drop down close to \$500 by this time next year. That still may be high for your pocketbook and there are other options.

As previously discussed in this series, you can get a raw signal input to the receiver by one of two techniques; use a big antenna and an LNA with not such hot specs, or, use a smaller antenna and a hot-spec LNA. If you set out to build your own antenna system, rather than buying commercially, you might be better off in this fast-changing technology time to invest in a little more steel and mesh and build a larger antenna going in, especially if you plan on having to purchase your LNA.

As recently as early in the past summer anyone who wanted to build his own LNA was pretty much stuck with working with 300-degree Kelvin type bipolar transistors. The belief was that any home constructor attempting to work with the touchy, and hard-to-make-work GaAs-FET amplifiers was probably asking for a quick way to lose a \$100 bill; that being the going price for the GaAs-FET transistors these days

from Hewlett-Packard (HFET 2201). However, during the recently completed Satellite Private Terminal Seminar this past August 14-16 in Oklahoma City, several home terminal builders demonstrated two- and three-stage GaAs-FET amplifiers they had constructed for between \$225 and \$350 that gave an excellent account of themselves against commercial amplifiers costing three to four times as much. This major achievement has changed the name of the private or backyard terminal game for the home constructor.

Well now; if a chap in Arizona can build a 10-foot by 10-foot spherical reflector and feed for \$500 or less, and you can build your own GaAs-FET low-noise amplifier on the kitchen table for \$350 or less, that starts to get the home-constructed terminal down to an affordable price does it not? What about the receiver?

### Receivers

In 1976 the first satellite video receivers around came into the cable television field via the Intelsat or international satellite marketplace. They cost upwards of \$10,000 and were literally hand wired and hand aligned.

By early 1978 the price for essentially the same receiver was down to about half that; perhaps \$5,000. But there had been only minor changes in the original design. The price reductions were largely due to slightly more volume production, and of course competition.

Needless to say many people were working on bringing the cost down; way down. Most however were involved in the cable TV, broadcast TV and other commercial market areas where nobody really expected receiver prices to drop much below say \$3,000 for many years to come. Outside of these broadcast related industries other engineers with a totally different set of markets in mind were quietly doing their own developmental work. Their goal was a \$3,000 complete terminal; including the antenna and the LNA.

By mid-1979 some inter-receiver marrying had taken place. Commercial receivers are available in two formats; some tune only one channel and to change channels you have to either change crystals or go through some sequence of screwdriver adjustments, or both. Not exactly what the home viewer accustomed to detent tuning has in mind. The other commercial receiver format is called "frequency agile" and that means you push buttons or twirl a knob and the full set of 12 (or 24) satellite channels flips by in front of you. By mid-1979 some of the commercial receivers in the single channel format were down under \$2500 list price while the tuneable versions were just a tad above \$3,000.



Let's stop for a minute and study Fig. 2. To appreciate what is involved in a satellite television receiver, we ought to understand what it has to do.

In a commercial installation the LNA (which mounts at the antenna, usually married to the feed-horn or focal-point antenna) has to develop sufficient RF signal voltage gain, at 4 GHz, to (1) drive the microwave signal through the interconnecting coaxial cable and into the receiver, and, (2) provide sufficient signal gain to establish the noise figure of the LNA as the noise figure for the whole receiving system.

The typical satellite TV receiver has a relatively high noise figure; 10-12 dB is not uncommon. To attempt to use such a high "front-end" noise figure to receive the weak satellite signals would be a mistake. To lower the noise figure to a more usable level (such as under 2 dB) requires not only a low-noise LNA but sufficient gain in the LNA stages to override the noise contribution by the 10-12 dB noise figure of the receiver. As a rough rule of thumb you need between 2.5 and 3 times as much voltage gain (in dB) as the noise figure (also in dB) to establish the new, lower noise figure of the LNA as the noise figure of the system as a whole.

Back now to Fig. 2. To keep unwanted energy out of the receiver (and there is plenty of unwanted or off-frequency energy floating around microwaves these days) the typical commercial receiver has a pre-selector (either totally passive or active plus passive) at the input. This is followed by a "high frequency-mixer" that combines the incoming (3.7 to 4.2 GHz) signals with a local oscillator signal source generated within the receiver to produce a new lower frequency (IF) output. Gain is

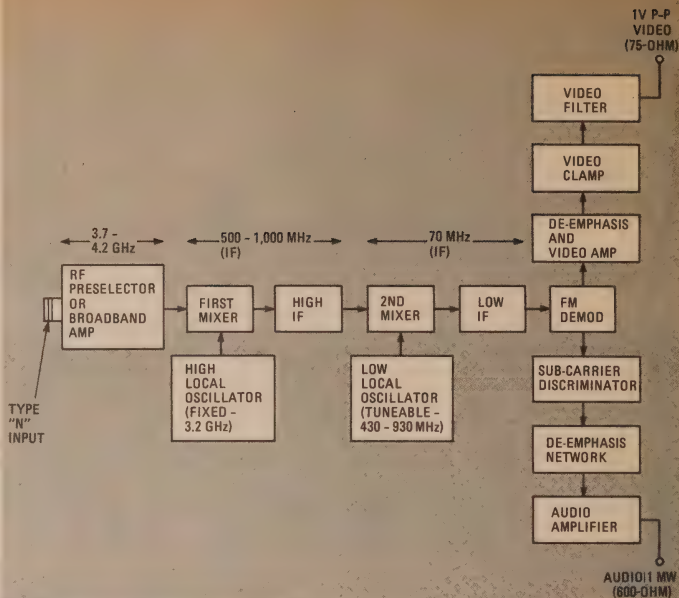


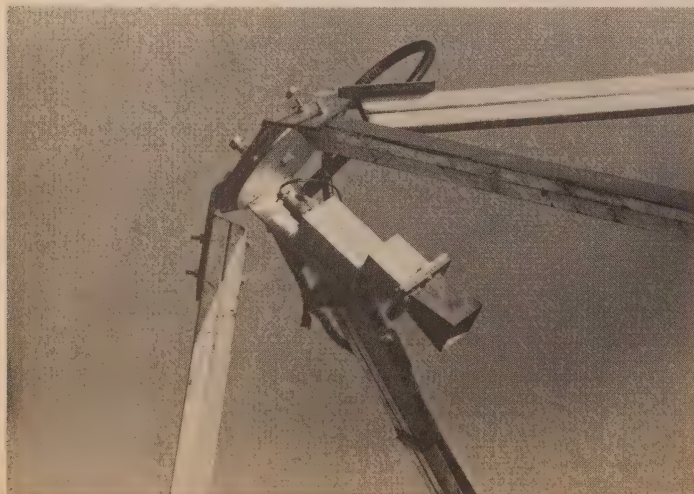
FIG. 2—MOST COMMERCIAL RECEIVERS use high-gain (50 dB) LNA's mounted at the antenna capable of driving 4-GHz region signals through several hundred feet of 7/8ths inch line to the indoor receiver. Typical receiver has either double conversion (approach shown here) or single conversion directly to IF. In receiver design shown, a 3.7- to 4.2-GHz preselector often has enough gain to bring the input RF level up to an adequate voltage to drive the first mixer. Relatively high-level high-frequency local oscillator (3.2 GHz is shown in example) may measure +10 dBm or more. With local oscillator on low side, high IF of 500-1,000 MHz is attained to drive second mixer that down converts to 70-MHz low IF. Oscillator for second local oscillator is voltage- or capacitive-tuned to produce 70-MHz low IF with inputs over full 500-1,000 MHz range. FM demodulator (discriminator) produces basic baseband signal that processes up for video to a de-emphasis circuit and video amp, then to a video clamp to eliminate the 30-Hz energy dispersal waveform, and then to a filter circuit. Audio processes down through separate (6.8 MHz) discriminator, de-emphasis network and audio amplifier.

then applied at the high-frequency IF and then the signal goes through yet a second mixer that further down-converts the high IF to yet a lower IF. This lower IF is often 70 MHz although there are some variations to this rule in

commercial receivers. When we finally reach the lower IF, we have gone through a pair of down conversions each employing a high-quality mixer and a high-quality local oscillator. If this is a frequency-agile (i.e. tuneable) receiver the first mixer is driven by a tuneable local oscillator source while the second mixer is driven by a fixed local oscillator source. Just for dollar reference, we are looking at using \$75 to \$100 mixers in these applications and the local oscillators are priced in about the same range. If this suggests that microwave components or modules are not cheap, you read the message correctly.

Once at the low IF we are ready to go to work on the modulation itself. Gain at a relatively low IF such as 70 MHz is inexpensive these days and 40-50 dB of gain in this range is typical. When the twice-down-converted signal is built up to a sufficient voltage level, it is ready to be demodulated. Remember that the video is frequency modulated onto the carrier, and the audio coming along with the video is further frequency modulated as a sub-carrier. This says that we use discriminators to demodulate the video and the audio in our detection system.

By removing the video signal out of the IF signal with a detector, we end up



HORN ANTENNA/LNA combination points directly towards the dish antenna. Coaxial cable is used to connect the LNA to the receiver.



with what is called baseband; that means pure video in this case. Only because the audio is carried along as a 6.2- or 6.8-MHz add-on or subcarrier, when we demodulate to baseband video we also have a aural subcarrier in the baseband output. By using a low-pass filter for the video and a high-pass filter for the aural subcarrier, we can then separate the video into one chain for further processing and the audio into another.

The video is preemphasized at the uplink transmitter site as a means of increasing the system performance and at the receiver we need to deemphasize to establish the original baseband video characteristics. The deemphasis network is strictly an L-C network and is not complicated. Next in line for the video is a video clamp circuit that may mystify you if you are accustomed to normal video techniques.

Video at the uplink site is "frequency-dithered" or dispersed at a 30-Hz rate as a means of reducing potential interference between strictly terrestrial 4 GHz video circuits (such as the telephone companies employ) and the satellite service. The easiest way to clean up the dispersal waveform is to shove the video through a clamping circuit. If you clamp something like this *hard* enough, the 30-Hz waveform simply goes away. Finally a bit of passive video filtering and you are in business with baseband video (typically 1 volt peak-to-peak).

Over on the audio side, after passing the 6.2 or 6.8 MHz aural subcarrier through a frequency filter that eliminates the video baseband information, the signal is fed into yet another discriminator (detector) that recovers the audio. From here it goes through yet another deemphasis network (this one for the audio) and finally an audio amplifier. Most commercial receivers release the audio across a 600-ohm balanced output line.

If you are engaged in the television receiver servicing industry, you may be asking yourself why this should cost between \$2500 and \$3500 a pop. If you are new to receivers in general, you probably have the opposite reaction.

As we shall see in the next part of this series of articles, several experimental or private terminal builders have asked themselves the same thing. One terminal builder, Taylor Howard

of California, has managed to assemble the LNA (a bipolar unit in his case) and the receiver for around \$1,000. He did this back in 1976-77 when parts were considerably more expensive and we estimate you can do it today for under \$700.

Assuming you don't want (or need) to start off with a bag full of new parts, and can assemble some equipment from other services into a satellite TV receiver, just how simple can it really be? Well, a man in South Carolina by the name of Robert Coleman has put together a 10-foot dish, a two-stage GaAs-GET LNA and a complete receiver for around \$500! His "secret," if you can call it that, is that he is a sharp attendee of Hamfests and other outlets where *surplus* electronic equipment is brought out for sale at often just a few pennies on the original dollar value. The Coleman approach is a good one, but it requires being able to trace down surplus parts, modules and components that may not be a good supply because of limited production runs many years (or decades) ago. Still, if this approach does interest you and you are not afraid to go into the surplus market to look for parts, there is help available for you in this specialized area.

Suppose you wanted to try a cross between building a complete terminal receiver from scratch and assembling one from surplus equipment? Well, that is an approach many people have followed, largely patterned after the work done by English satellite TV experimenter/pioneer Steve Birkill (amateur G8AKQ). The Birkill receiver is similar to that shown in Fig. 3. The LNA is a bipolar system of three to five stages using Hewlett-Packard HXTR (6102 and 6101) transistors. For those who want to investigate this particular approach, Hewlett-Packard Application Note No. 967 tells how to build a stage of this amplifier at 4 GHz (a multiple stage-device is simply several separate stages cascaded together).

The Birkill Receiver places the LNA stages at the feed antenna, follows that with a double-balanced mixer (also located at or near the feed) and the mixer is driven by both the input 4 GHz range signal(s) plus a "free-running" oscillator operating at around 3,200 MHz. There are several ways to derive the local oscillator injection signal; one of the easiest is to use a completely self-contained oscillator. One of the 8360-family of oscillators manufactured by Avantek, Inc., 3175 Bowers Ave., Santa Clara, CA 95051 will do the job nicely. This TO-8 packaged device has four pins on it; one for the positive operating voltage, another for a ground, a third for the RF output in the gigahertz region and a fourth for a tuning voltage that allows you to run the oscillator through a 500-MHz span. Most homebrew (from

scratch) satellite TV receiver builders are using this approach because it eliminates all work at microwave frequencies in deriving the high local oscillator signal.

The Birkill Receiver approach, modified slightly, is shown in Fig. 3. As you can see, the LNA, the high-frequency local oscillator and mixer, plus a bulk gain stage operating in the 500-to-1,000 MHz region is mounted outside at the antenna. This simply means that what you feed "downstairs" to the remainder of the receiver, through coaxial cable, is (relatively speaking) low-frequency signals; in the 500-to-1,000 MHz region in this case. If the run is 100 feet or less, you can get by at these frequencies with RG-8 type coaxial cables whereas a similar run at 4 GHz requires 7/8-inch air-dielectric cable and special fittings.

Once indoors, the Birkill Receiver approach treats the signals contained in the 500-to-1,000 MHz IF bandwidth as a "group" and tunes them separately with a slightly modified (English, Mullard) UHF television tuner. The TVRO signals are 36 MHz wide (and of course still FM) and we need to convert them again (in frequency) down to a low enough IF where they can be detected. Experimenter Steve Birkill has found that an English Mullard type ELC1043/05 UHF TV tuner makes a dandy tunable second conversion system with only minor modifications. Unlike U.S. (of Canadian or Japanese, etc) UHF tuners designed for the American NTSC signals, the English (Mullard) tuner is capable of passing the full 36 MHz wide TVRO signal with only very minor modification. All American tuners checked have a 3 dB passband of not more than 10 to 11 MHz which simply means that they are not wide enough (even if modified) to handle the extra modulation/carrier width of the TVRO signal. Another advantage of the (European) UHF tuner, in this application, is that it has 20 dB of RF (500-1,000 MHz) gain and a quite respectable noise figure of under 5 dB. American market UHF tuners lack RF amplifier stages and consequently their front end noise figures are in the 12 dB and up region.

Birkill takes his low IF out at 35 MHz which allows him to use a Signetics 561 phase-locked-loop as a demodulator. Many of the commercial receivers also use phase-locked-loop demodulators, but Birkill's approach is unique since it allows the system user to change the effective bandwidth of the total system by varying the way the 561 is driven. This allows you to capture (that is, see) signals that are far weaker than would register on a standard 30- to 36-MHz wide IF satellite receiver; although admittedly the quality does suffer in the process. However, in his case, Steve Birkill has been able to produce very high quality reception from the Russian





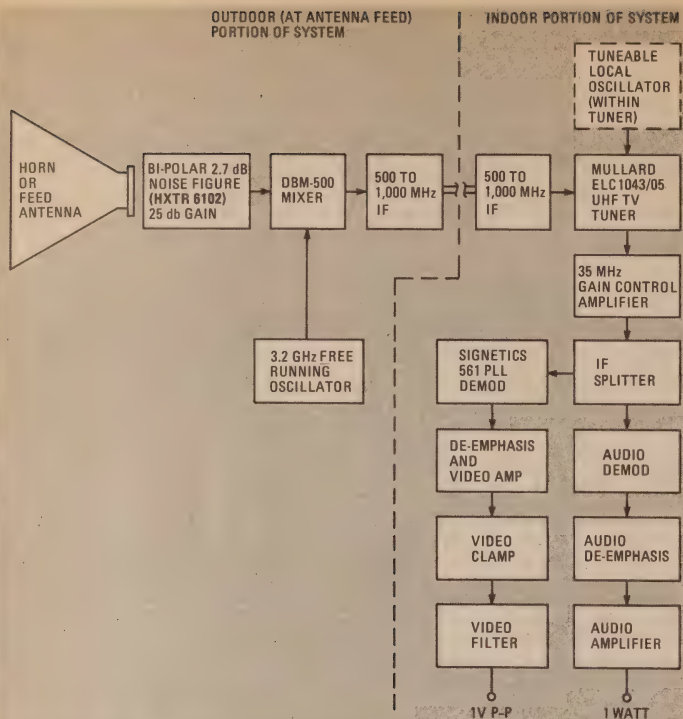


FIG. 3—MOST HOMEBREW TERMINALS place a lower grade LNA stage plus first mixer, local oscillator source and an IF stage or two at the feed antenna, coming down to the baseband demodulator through lower-cost 50-ohm cable at the high-IF (500-1,000 MHz) region. In this version, essentially patterned after English experimenter Steve Birkill, a Mullard ELC1043/05 (European) TV tuner is slightly modified as combination oscillator and mixer to translate high IF range down to 35-MHz region low IF. Birkill processes his 35-MHz IF to video through a Signetics 561 phase-locked-loop demodulator; a system that offers advantages for weak input level signals. Full block diagram is not shown at this time.

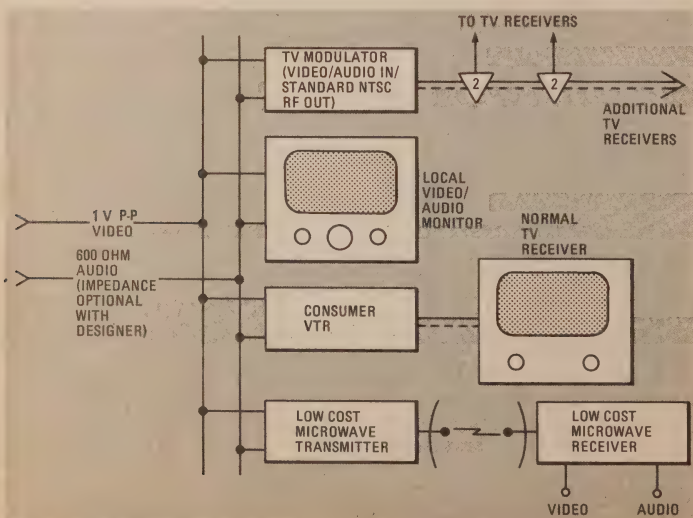


FIG. 4—VARIOUS METHODS OF DISPLAYING BASEBAND (i.e. demodulated) video and audio. Typical receiver produces 1VP-P video and some usable level of audio (often at 600-ohms balanced although that is design decision of builder). Baseband signals will directly drive TV channel RF modulator, a high-quality video monitor (with audio display system built-in or separate), a consumer VTR (for recording or as loop-thru to use RF modulator), or low-cost (private) microwave system.

stationary series of satellite transponders although he is working with signals 7-9 dB weaker than we have available here from North American domestic satellites, and he has acceptable (if not high quality) pictures from the much weaker Intelsat satellites (they run from 12 to 15 dB weaker than our domestic satellites). The balance of his receiver approach is pretty standard since once you have baseband video and audio there is only about one way to process it for conversion back to RF as an AM format signal.

To some people, being at baseband with the signal may seem like ending up at the wrong place. To view baseband directly, you feed the video and audio signals into a video "monitor" and a speaker. Not everyone has a video monitor of course and some means of getting the baseband signal back to a standard NTSC television channel (with the video portion amplitude modulated) is required.

A word about viewing the signal(s) at pure baseband; i.e. into and through a video monitor. This is the ultimate (high class) viewing technique since the baseband signals are of very high quality (48- to 54-dB signal to noise) and purity. However, this generally limits you to viewing the signals on a single monitor since video monitors tend to be expensive.

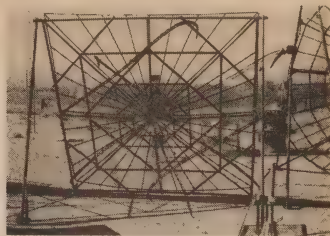
In Fig. 4 we have several methods suggested to get the baseband back to an RF channel. Clearly the baseband video and audio must be used to modulate a TV channel modulator device. Numerous circuits for these devices have appeared in **Radio-Electronics** through the years. One of the easiest ways to modulate back to RF is to use a LM1889 IC which is a complete (TV channel 3 or 4) RF carrier generator/modulator intended for TV games and home VTR's. If you already have a home VTR, you can simply loop the baseband video and audio to the home VTR's "camera" and "audio" inputs. This turns the VTR into a modulator for you and you can then watch the satellite TV signals on multiple TV receivers, connected to the VTR modulator through 75-ohm coaxial cable (as in a miniature TV distribution system).

R-E



# BUILD THIS

## LOW COST BACKYARD SATELLITE TV EARTH STATION



TEN FOOT SWAN SPHERICAL is almost opaque although aluminum screen mesh reflector surface is in place. Note Swan's use of squares and spokes to create sandwich layers that rigidly support antenna and reflective surface. Antenna tilt is handled by telescopic rear support rods with lower-ground-tilt on hinges.

*Now you can build your own Satellite TV Earth Station in your own backyard for less than \$999. This month we'll take a look at antenna design and how a spherical antenna can be built and erected.*

ROBERT B. COOPER, JR.

IN THE AUGUST, SEPTEMBER AND OCTOBER 1979 issues of **Radio-Electronics**, we discussed the evolution of the geostationary satellite service for North America and described the basics of its operation. In the January issue we looked at the hardware in the receive portion of the system and discussed the various approaches to hardware design. We are now ready, with this foundation, to begin the task of designing your first satellite television earth receiving terminal.

### Design versus cost

If money is no object, you probably are more apt to buy a private satellite terminal than to build one (or portions of one). A list, current through the preparation of this article, of firms specializing on a national or regional basis in the sale of complete TVRO receiving systems (either 'turn-key installed' or on a hardware piece by piece basis) appears in Table 1. The bottom line is that you can purchase a first-rate commercial grade terminal for around \$5,000 in hardware costs (and install it yourself) or have the job done for you with every wire in place and every nut and bolt secured for less than \$10,000.

By building the terminal yourself, you are able to look carefully at the many design variations available and thus select the various module and sub-assembly approaches that best

suit your own needs and talents. And in fact, because there are so many excellent designs around, we have already engaged in a bit of this selection process for you. We will lead you step-by-step through the various choices so that you will wind up with a complete terminal that best fits your needs.

Our approach is not to follow any single design philosophy. The *Howard Terminal* system, widely copied and very good in performance, may be a bit on the complicated side for a non-experienced builder. The *Coleman*

*Terminal*, originally largely assembled from surplus (Bell-system discarded) microwave equipment, is in turn perhaps too much of a hit-and-miss proposition since the builder must locate many suddenly hard-to-find second hand microwave pieces to make it all play.

The antenna portion is a similar case in point. Six months ago you had three choices; locate a surplus or used parabola, buy a new parabola, or, build a parabola. Many hundreds of people were turned onto satellite TV and then subsequently turned off because they couldn't locate a surplus parabola, didn't have the spare cash to purchase a new parabola, and felt unqualified to construct a homebrew one. Now, with the passage of time, a really low-cost, high-performance non-parabolic antenna has made its appearance, we shall shortly see.

Our design philosophy here will be to simply borrow the best technology that exists at this time from several different sources. We'll make you this promise. Over the next few issues of **Radio-Electronics**, you'll learn how to build your own complete terminal, including antenna, an ultra-low noise GaAs-FET LNA, and a twenty-four-channel frequency-agile receiver that ends up at VHF channel 3, 4 or 5 with a modulated NTSC RF output for under \$1,000. You read right ... the whole,

TABLE 1

Suppliers currently offering turn-key-installed home satellite receiving terminals and those who also offer hardware for do-it-yourself installations (\*):

1. **Channel One, Inc.**, 68 Avalon, Newton, MA 02168
2. **HOMESAT, Inc.**, 3845 Pleasantdale Rd., Atlanta, GA 30340 (\*)
3. **Gardiner Communications Corp.**, 1980 S. Post Oak Rd., Houston, TX 77056 (\*)
4. **Microdyne-AFC**, 627 Lofstrand Lane, Rockville, MD 20850 (\*)
5. **Satellite Television Systems**, Box 11249, Reno, NV 89510
6. **USTC**, P.O. Drawer 'S', Afton, OK 74331
7. **Spacecoast Research**, Dept. B, Box 442, Altamonte Springs, FL 32701



complete terminal, including antenna, for under \$1,000.

## Where do you put the gain?

There is passive and active gain required in the system. In the antenna portion (passive gain) the minimum gain required is a function of where your location falls on the satellite's EIRP pattern (see the September and October 1979 issues for a complete explanation). For discussion, we'll say you need at least 40 dB of passive gain in the system. That's a ten-foot minimum reflector surface any way you cut it. However, a 12-foot surface is even more desirable.

The decision on how much gain to design into the active portion (i.e., the LNA and the receiver) is more difficult to make. That's because we need signal gain for two reasons:

1. To amplify the 4 GHz signal voltage to a level where the demodulator can recover video (and audio) from the satellite signal, and,
2. To overcome (or override) the receiving system noise temperature.

Ideally, system noise temperature is set entirely by the low-noise capabilities of the first LNA stage(s). In the real world, the noise factor for the system is typically set by this *plus* the internal noise figure of the receiver stages. There are two types of 'noise' to be considered in the receiving system. Every amplifier stage (even a video amplifier) has a noise factor. However, when computing noise figure, it is often convenient to look at any device in the receiver that has 'loss' as a noise source as well. In this regard, a mixer stage (i.e., a stage that converts one incoming frequency to another outgoing frequency) has loss and therefore it contributes 'noise' to the overall system.

In modern receivers there are two approaches to getting the 4-GHz satellite input signal down to a low enough frequency where the modulation contained on the carrier can be demodulated to baseband. A single conversion receiver (i.e., the Coleman approach) takes you from 4 GHz to an IF of 70 MHz in a single conversion (or mixing) step. A double-conversion receiver gets you to 70 MHz from 4 GHz in two steps; the first typically takes you down into the 1.2-GHz region (although the selection of a high IF is entirely up to the receiver designer and could be any place from 500 MHz to 2,000 MHz) while the second mixes on down to the pretty much standard 70-MHz region.

The design approach we are going to follow here is the single-conversion option. However, this is offered with the understanding that in some ways the performance of a double-conversion receiver is superior to the single-con-

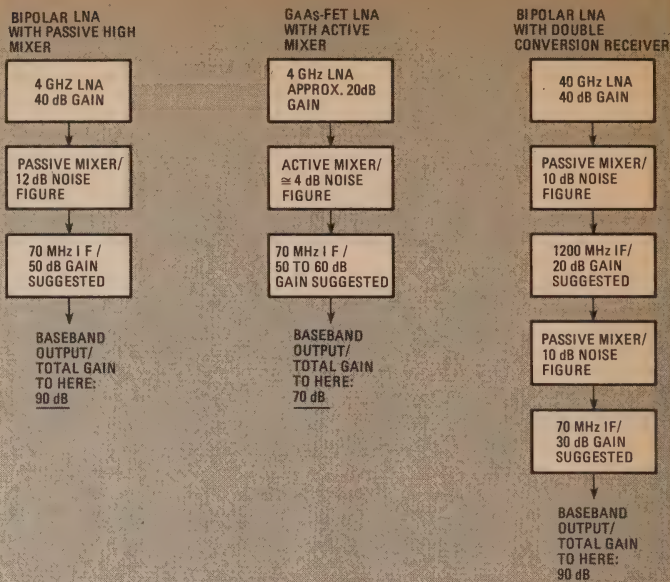


FIG. 1—GAIN REQUIREMENTS for three receiver approaches. Single-conversion receiver with bipolar LNA and passive mixer is shown in a. Single-conversion receiver with GaAs FET LNA and GaAs FET active mixer is shown in b. Double-conversion receiver with a bipolar LNA is shown in c.

version design set forth. In a double-conversion receiver, image rejection, stability and perhaps even selectivity can be better than in a single-conversion design. But, double-conversion techniques are more costly. They require that you have access to test equipment that you probably do not have available (adjusting and aligning a 1.2 GHz high IF does require some equipment not commonly available); and for home use, the trade offs seem to favor the single-conversion approach.

At the risk of oversimplifying the rationale for choosing a single-conversion approach, see Figure 1. Here we see that double conversion has a price tag attached to its 'perhaps' superior performance; you need more total system gain in order to make the double-conversion system perform properly. And gain not only costs money in parts and time, it also increases the complexity of the receiver.

Note in Fig. 1 that we are looking at:

1. A single-conversion receiver using a bipolar LNA and a totally passive mixer (left hand side); the gain required is 90 dB.
2. A double-conversion receiver using a bipolar LNA; the gain required is 90 dB (minimum).
3. A GaAs-FET LNA front end followed by a GaAs-FET active mixer that single-converts down to the 70 MHz IF; the gain required is 70 dB.

In all fairness, one could design a double-conversion receiver with an active GaAs-FET high mixer and this would in turn reduce the total gain re-

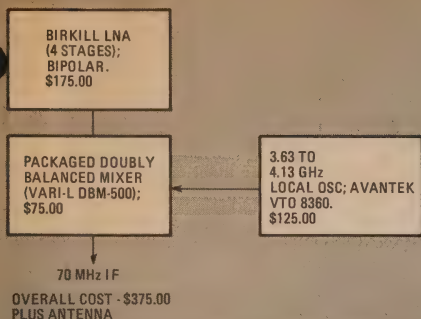
quirements of the system since our 40 dB of LNA gain is largely predicted upon the noise-factor contribution of that first mixer stage (the one that gets us away from 4 GHz). However nobody has yet done this and as we are sticking with proven designs at this point the comparison of gain requirements remains valid for now.

What does all of this mean? Simply this. If you wish the system-noise temperature to be determined by the first LNA stage(s), and we do, we have to build enough total gain into the system at 4 GHz to insure that the noise contribution of that first mixer is overridden by the LNA stage(s) in front of it. By replacing the passive mixer (the mixer that gets us away from 4 GHz down to a lower IF) with an active mixer, we shift the noise contribution (i.e., mixing loss) of the first mixer out of the loss column and replace it with a gain or in the worse case a unity-gain device that makes no significant contribution to the system-noise factor. So where we previously required gobs of gain at 4 GHz to overcome the noise factor or mixing loss of the high (or only) mixer stage, we now require much more modest amounts of gain to establish our LNA first-stage noise figure as the primary noise factor in our electronic receiving system.

Electronic gain is least expensive to come by at the lowest frequency to be used in the RF portion (the 70 MHz IF) but unfortunately we cannot place all of the gain here. Some gain must go at 4 GHz as well. In Fig. 2 we see two options open to us.



# OPTION ONE



# OPTION TWO

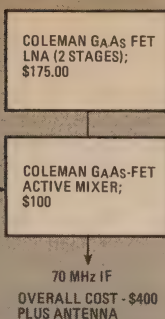


FIG. 2—TWO DESIGN APPROACHES to receiving satellite broadcasts. The Birkill approach is shown in option 1 while the Coleman approach is shown in option 2.

1. As the balance of this article installment shall show, the most cost-effective approach to the antenna today is the Swan Spherical TVRO antenna. If you are not a particularly sharp trader or buyer you will still be hard pressed in most sections of the U.S.A. to spend more than \$300 building this antenna.

2. In option one (Fig. 2) we could build a four-stage bipolar LNA (the so-called Birkill HXTR series LNA named after its developer Steve Birkill), follow this with a state-of-the-art doubly-balanced (passive) mixer such as the VARI-L DBM 500 4 GHz to 70 MHz (IF) package, and end up at 70 MHz with a total cost to that point of \$675 including the antenna.

3. In option two (Fig. 2) we can build a two-stage Coleman GaAs-FET LNA and follow this with a single-stage Coleman GaAs-FET active mixer, again ending up at a 70 MHz IF for a total material cost of \$700 including the antenna.

This would seem to suggest that the two approaches in getting 4 GHz energy out of the air and down to a manageable IF such as 70 MHz are very similar in cost. The truth is that the option-one approach has probably just about come to a resting place in costs (for the next year or so) while the GaAs-FET-approach is still largely dependent upon the \$80 to \$100 price tags on the GaAs-FET's themselves. With GaAs-FET prices starting to tumble, the cost of this approach may well be down another \$100 or so before spring. That's one reason to seriously consider this approach. Another more compelling reason is that this approach uses far fewer devices overall; and as those Murphy Law believers know well, the more stuff you cram into a box, the more apt something is to go wrong when you can least afford the time or expense to fix it. Note that in both approaches we are using a newly avail-

able Avantek VTO 8360 oscillator module to provide the local-oscillator drive to our chosen mixer. We'll look more closely at the VTO 8360 in the next part of this series of articles.

Finally, in Fig. 3, we see how we are going to process the 70 MHz IF signal and what it is going to cost us. We have some gain stages at 70 MHz, a demodulator to extract the video modulation from the 70 MHz IF signal along with a few relatively simple baseband processing circuits, a demodulator to create audio from our 6.8 (or 6.2) MHz aural subcarrier, a VHF modulator to convert our baseband video and audio back to a NTSC compatible VHF TV channel (such as channel 3, 4 or 5) and a power-supply section which will provide operating voltages for the system. The total system cost (if you want to start budgeting your pennies now) is as follows:

1. Swan Spherical TVRO Antenna; \$300 (or less)
2. 4 GHz front end to 70 MHz IF segment; \$375 to \$400
3. 70 MHz IF, baseband processing and VHF TV channel modulator with power supply; \$250.

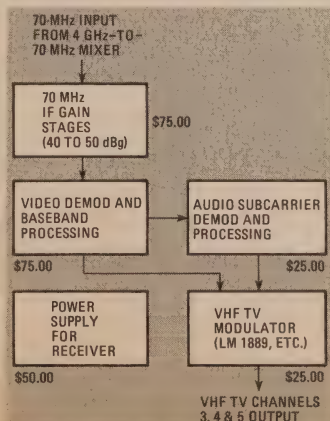


FIG. 3—METHOD AND COSTS of converting the 70-MHz IF to a VHF RF signal suitable for connecting to the antenna terminals of a TV receiver.

That brings us sufficiently in under \$1,000 to allow you to indulge in some packaging of the system following a card cage approach if you wish and still have a little change left over for unexpected expenses.

## Swan spherical TVRO antenna

There are several excellent reasons why the Swan TVRO antenna design is the best and most logical choice for the home builder:

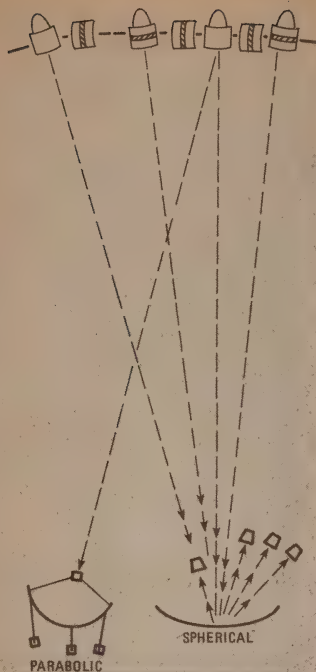
1. **Materials**—Everything called for can be procured locally. Steel or aluminum pipe, tubing (round or square stock) plus aluminum window screening, and common hardware such as machine bolts, are all that is required for the reflector system. The feed-antenna is constructed from galvanized sheet metal.
2. **Cost**—\$300. Give or take very little. Although, if you are a good shopper in metal yards you might shave as much as \$100 from the total cost.
3. **Complexity**—Far less complex to create the 'spherical surface' design than to create a comparable parabolic surface. The principle is easy to grasp and uncomplicated to duplicate.

These factors alone should make the antenna very appealing. However there is a golden bonus with the spherical sections; the antenna is capable of 'looking at' many satellites at the same time. See Fig. 4.

The spherical antenna has such a gentle curve to its surface that it can "see" a 40 degree wide portion (or span) of the orbit belt effectively. The antenna is fixed, permanently, on the ground with the center pointed in a predetermined direction. We'll see how that works shortly. Every geostationary point-source in front of the antenna has a focus point out in front of the reflector surface. But this focus point changes for different angles of arrival. A satellite located directly on boresight will have its focal point directly in front of the center of the Spherical surface while a satellite west of the boresight point will focus slightly east of the center point. Conversely, satellites east of the boresight focus slightly west of the center point.

With this geometry, one moves the location of the focal- or feedpoint-antenna (left and right along a line parallel to the reflector surface) to switch from one satellite to another satellite. If you can leave the reflector stationary and move only the focal-point (or pickup) antenna, could you not actually install two or more pickup antennas so as to simultaneously receive two or more satellites? The answer is yes; something that cannot be done with a normal parabolic antenna.



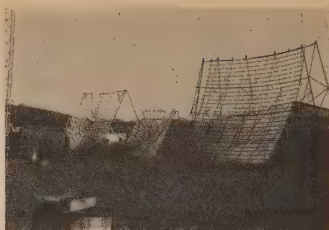


**FIG. 4—PARABOLIC VERSUS SPHERICAL antennas.** Normal parabolic dish antenna focuses all incoming energy onto a single focus point and as a result receives only one satellite at a time. To receive a different satellite the parabolic antenna must be redirected. The less radical curvature of a spherical antenna permits simultaneous reception of numerous satellites spread over up to 40 degrees of sky arc. Different satellites within the 40-degree arc can be received by moving the focus-point antenna or multiple satellites can be simultaneously received by using multiple focus point antennas.

#### How does it work?

Both the parabolic and the spherical reflector surfaces work on the same principle. The reflector surface is curved, in both dimensions. A 'cup' is formed and the center of the cup on a parabolic is directly in line with the satellite. All of the energy that is intercepted by the reflector surface is redirected towards a central focus-point. In a good efficiency parabolic antenna, approximately 55% of the total energy intercepted by the reflector surface ends up within the feed- or focal-point antenna.

But, the curve of the spherical antenna is very shallow; it is curved (or indented) sufficiently to cause the energy to focus but not so curved as to cause the RF energy to only focus when the reflector's center and the satellite are in-line together. In Fig. 4, we have a slightly exaggerated illustration of the primary difference between the parabolic (on the left) and the spherical reflector surfaces. The parabolic, because of its boresight requirement, 'sees' only a single satellite (or



**FIG. 5—THREE SWAN SPHERICALS** at the Bisbee, Arizona test range of Oliver Swan. From left to right, 14-footer, 10-footer and huge 19-footer on right.

spot in the sky) at a time. The spherical sees every satellite location along the orbit belt over a region  $\pm 20$  degrees from boresight (the center of the reflector straight ahead). Actually, the spherical surface can 'see' farther than that but the focal-point antenna has difficulty recovering wavefront energy offset from the boresight heading by more than 20 degrees. Look closely at Fig. 4; several separate feed-point antennas (the squared-off cups) are in place, each receiving energy from a separate satellite along the belt. Figure 5 shows three spherical antennas.

#### SATELLITE TV COLUMN

To keep you abreast of the latest happenings in this exciting new field, a monthly column entitled "Satellite TV News" will appear in **Radio-Electronics**. This column will keep you informed of the latest technological developments, equipment designs, and satellite broadcasts.

*Note:* The preceding material may not prove sufficiently detailed for the novice in this field. The *Swan Spherical TVRO Antenna* manual is some 30 pages in length and provides complete step-by-step instructions for those uncomfortable with the brevity of this quick outline.



# BUILD THIS

IF YOU'RE A REGULAR READER, YOU'VE heard about TVRO stations—special setups used by cable-TV companies and others to receive the four-gigahertz (4,000 MHz) signals from satellites.

One of the most expensive components of a TVRO system is the antenna. The 8-Ball antenna described here is one of the few that you can build yourself and is relatively inexpensive and easy to align.

With it, and a couple of other special components, you can watch blacked-out sporting events, commercial-free movies, and other choice television fare usually available only on cable-TV systems.

What you need in addition to the antenna are an LNA (a special Low-Noise Amplifier to boost the very weak signal picked up by the antenna) and a down-converter to process the 4-GHz TV signal so it can be viewed on an ordinary TV set. You can also purchase a special TV set that has a down-converter built into it if you wish.

Before going any farther, take a minute or two to study the various photographs of the antenna in various stages of assembly. The complete TVRO antenna consists of a 12-foot

## SATELLITE TV ANTENNA

*Before you can receive  
satellite television, you need  
the appropriate antenna.*

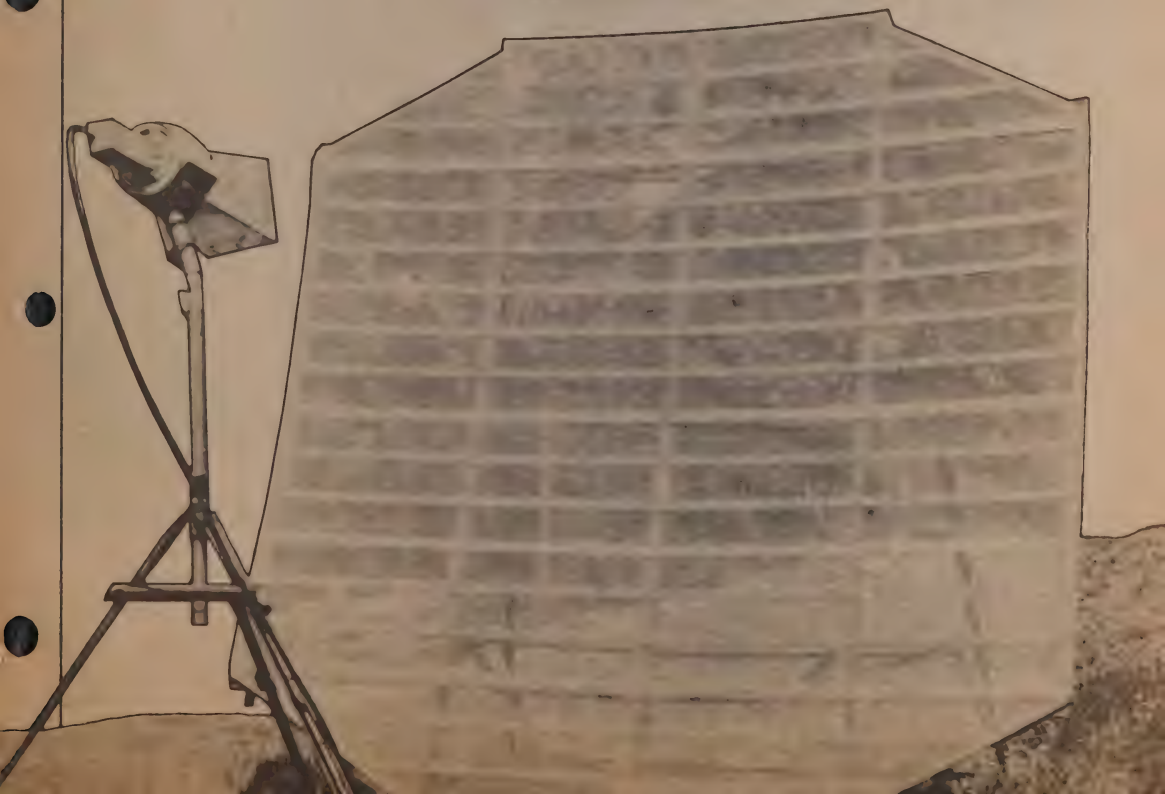
*This inexpensive  
design can be built  
from common materials.*

H.D. McCULLOUGH

"dish" or reflector that captures the incoming signal and focuses it at the waveguide horn feeding the LNA. This article covers the construction of the dish. The 8-Ball's dish consists of two main sections. One is the steel frame that provides a rigid, durable support fixture. The other is the wood-lattice assembly to which the reflector surface (screen wire) is fastened. An important feature of this type of construction is that it is not necessary to build the heavy metal frame to close tolerances. However, you should keep all the metal ribs within a half inch or so of their intended positions.

The redwood lattice is attached to the frame with adjustable bolts about every two feet vertically and every three feet across. Those bolts allow the lattice (hence the reflector surface) to be adjusted to conform to the precise curve required. When adjusting the antenna, the vertical wood strips should be set to within a sixteenth of an inch of the exact curve.

The steel frame (see Fig. 1) consists of three horizontal ribs (HR1, HR2, and HR3) and five vertical ribs (VR1 through VR5) plus the rear legs and braces. The frame is made from 1/8-inch thick 1 1/2 x





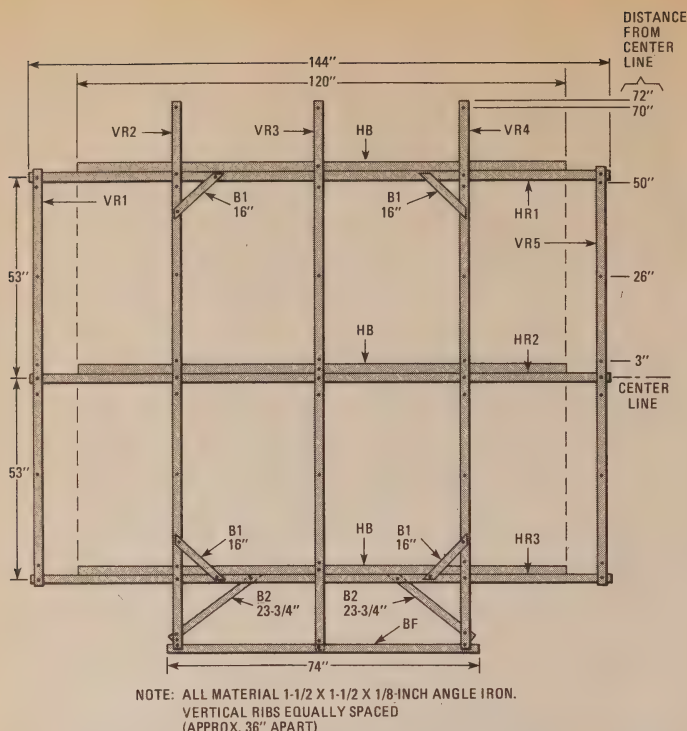


FIG. 1—THE METAL FRAME provides a rigid and durable support structure. The only critical factor in its construction is the setting of the angular bend in the three horizontal members.

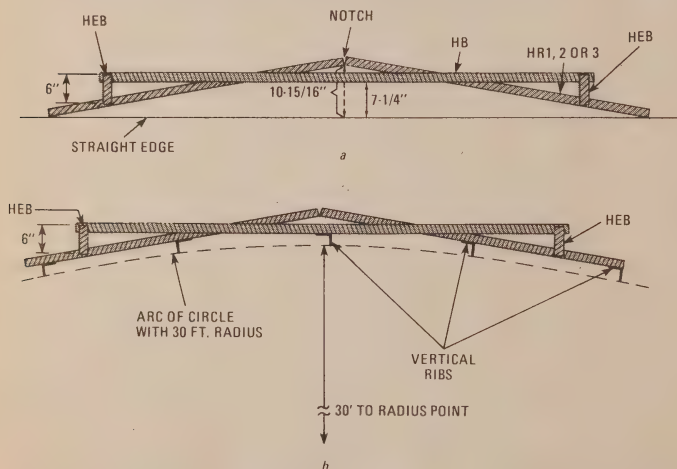


FIG. 2—THE HORIZONTAL CURVATURE of the 8-Ball reflector is developed by the bend in the horizontal ribs and by horizontal brace as shown in a. The five vertical ribs in b all lie on an arc that has a radius of 30 feet.

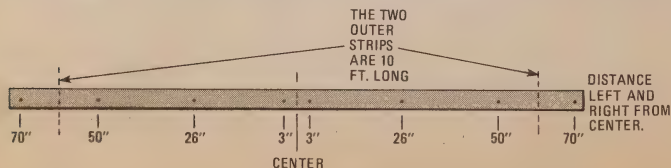


FIG. 3—THE FIVE VERTICAL LATTICE STRIPS are prepared by drilling holes according to the measurements shown. Three strips are 12 feet long with eight holes; two are 10 feet long with six holes.

1 1/2-inch galvanized angle iron. Each horizontal rib is cut through at the center so it can be bent (see Fig. 2-a) and secured with a brace (HB) and end braces (HEB). The angle formed should be approximately 163 degrees. To establish the precise surface curvature with a minimum of final adjustments, the angle must be set very accurately.

A very small error in the location of the bolt holes where the brace and end braces are attached to the horizontal rib will cause a large error at the ends of the rib. Position the rib and braces according to Fig. 2-a and clamp them together with "C" clamps or locking-type pliers. Drill the holes and set the pieces aside temporarily.

When the horizontal brace is properly shaped and bolted, the angle and location of the brace will be such that the five points on each horizontal rib where a vertical rib is attached will lie on a circle with a radius of 30 feet as shown in Fig. 2-b. The procedure just described sets the curve of the frame and, therefore, the reflector surface in a horizontal direction.

### Lattice preparation

There are five vertical lattice strips made of 3/4 x 3-inch redwood. Two of the strips are 10 feet long, and three are 12 feet long. Prepare them by drilling holes according to the measurements shown in Fig. 3. The strips can be stacked and all drilled at once; or, better yet, drill the three 12-foot pieces and then the two 10-foot pieces. The holes will take 1/4-inch bolts so use a 9/16-inch bit; assembly will be easier.

You'll need nineteen 12-foot pieces of 3/4 x 2-inch redwood stock for the horizontal ribs. Thirteen of those are used as-is. To get the angles at the corners of the lattice (see Fig. 4) cut two other pieces to 11 feet 4 inches, two pieces to 8 feet 10 inches, and two pieces to 6 feet 2 inches. The corner diagonal pieces will be covered later.

To establish the curve in the vertical direction, the five 3/4 x 3-inch redwood strips will be attached to the vertical steel ribs with adjustable bolts as shown in Figs. 5 and 6. Note that the spacing between the vertical steel rib and the vertical wood strip is identical for all five vertical ribs at any specific distance up or down from the middle horizontal rib. Thus, we see from Fig. 5 that all five vertical strips are touching the steel ribs at their centers, and that 24 inches up and down from center, the space between the wood strip and steel rib is 13/16 inch for all five of the ribs. At 48 inches from each side of center, the spacing is 3/32 inches, and it is 7/4 inches at 72 inches from center. The combination of the vertical curve formed by properly setting the adjustment bolts and the curve formed by the horizontal ribs will establish a precise reflector surface.



## PARTS LIST

**Frame:** The following are all 1/2x1 1/2-inch, 1/8-inch thick galvanized or primed angle iron.

Part no.	Length	Quantity
HR1	12 ft.	1
HR2	12 ft.	1
HR3	12 ft.	1
HB	10 ft.	3
HEB	6 in.	6
VR1	9 ft.	1
VR2	12 ft.	1
VR3	12 ft.	1
VR4	12 ft.	1
VR5	9 ft.	1
B1	16 in.	4
B2	23 3/4 in.	2
BF	74 in.	1
BR	104 in.	1
B3	32 in.	2
B4	59 in.	2
B5	30 in.	2
B6	30 in.	2
B7	83 in.	1
B8	92 in.	1
RL	8 ft.	2
RLX	4 ft.	2

**Wood lattice strips (5/8 or 3/4-inch redwood):**

Size	Quantity
2 in. x 12 ft.	22
3 in. x 12 ft.	3
3 in. x 10 ft.	2

**Bolts (1/4x20 thread):**

Length	Quantity
3/4 in.	72
4 in.	10
5 in.	10
8 in.	10
12 in.	6

**Miscellaneous (quantities in parentheses):**

1/4-inch nuts (196)  
 1/4-inch ID washers (72)  
 No. 8-1 1/4-inch brass wood screws (140)  
 aluminum screen (26 inches x 75 ft., 0.011 in. dia. wire, 1/16 in. mesh or heavy-duty 0.025 in. dia. wire, 1/8 in. mesh)  
 staples (rustproof)  
 glue  
 inclinometer  
 radius wire  
 anchor bolts (4)  
 "J" brackets (4)

**Note:** Some of these items will be called for in Part 2.

## Assembling the frame

Prepare each horizontal rib as shown in Fig. 2 by attaching braces HB and HEB with 3/4-inch bolts.

Next, place the three horizontal ribs on blocks and attach the five vertical ribs as shown in Fig. 1 and Fig. 7. Use 3/4-inch bolts. Note that, because of the braces, each horizontal rib will have a different number of holes drilled in it—so be sure to get the ribs in their proper positions. The top view in Fig. 2-b shows how the vertical ribs are posi-

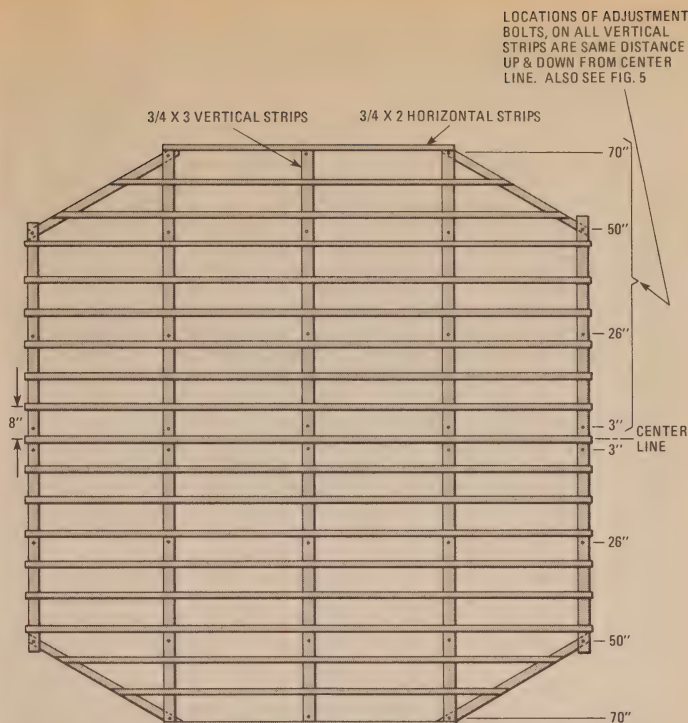


FIG. 4—THE REDWOOD LATTICE ASSEMBLY shows the locations of the 36 adjustment bolts. Those bolts set the curvature in a vertical direction. The arc of curvature is again 30 feet.

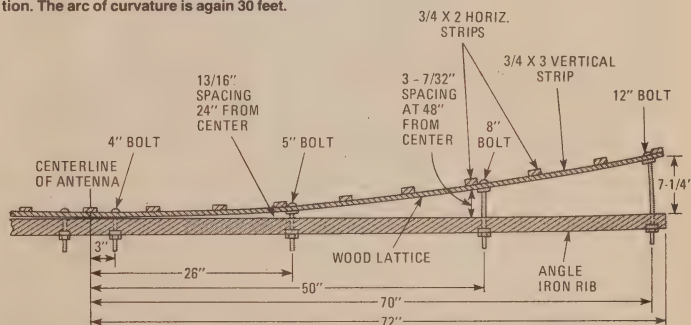
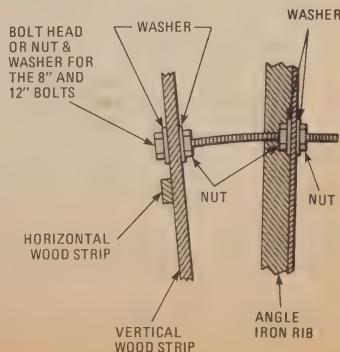


FIG. 5—SIDE VIEW of the top half of one vertical rib with wood lattice attached.

FIG. 6 (right)—DETAIL OF LATTICE ATTACHMENT showing use of nuts and washers on adjustment bolt.



tioned (note that the bottom of VR3 goes under BF).

Tighten the nuts only finger tight until all the pieces shown in Fig. 1 are installed and then tighten them securely. Whether assembling the 8-Ball from a kit, or from scratch, you'll find that some holes may not align perfectly. Make sure that everything is located properly, then align the holes with a tapered punch. Hold the pieces in place with clamping-type pliers while you insert the bolts.



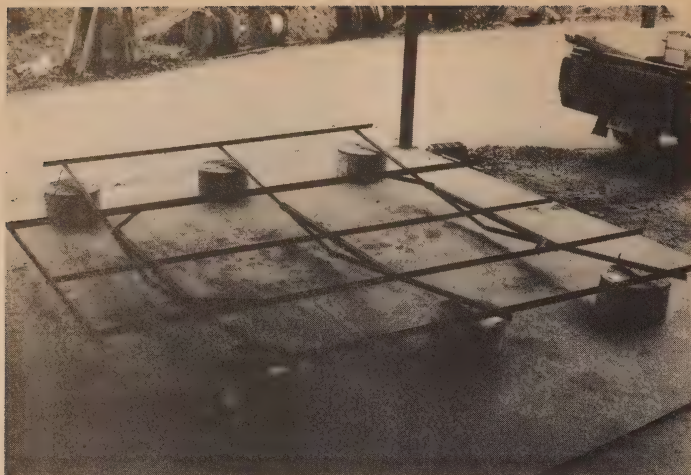


FIG. 7—THE THREE HORIZONTAL RIBS are supported on blocks while the three main vertical members are attached to the framework.

### Putting it all together

The next step is to assemble the redwood lattice as shown in Fig. 4. Mark all five vertical strips every eight inches (Fig. 8) for ease in positioning and installing the horizontal strips. Start at the

center and work outward—it's a good idea to displace the first mark half the width of a horizontal strip so that you can line up the edge of each  $\frac{3}{4} \times 2$  with one of the marks. All 19 horizontal strips are spaced on 8-inch centers except for



FIG. 8—MARK ALL FIVE VERTICAL STRIPS every eight inches to make installing the horizontal strips easier.



FIG. 9—ADJUSTMENT BOLTS are set for proper spacing between vertical frame rib and wood strip. Here a  $7\frac{1}{4}$ -inch spacer aids adjustment at 72-inch point.

The following are available from McCulloch Satellite Systems, PO Box 57, Highway 62-East, Salem, AR 72576: The 12-foot 8-Ball Satellite Television Antenna Kit, \$750.00. Includes everything except staples and concrete for mounting base. Frame is  $1\frac{1}{2} \times 1\frac{1}{2}$ -inch angle iron with all pieces cut to fit and drilled. One coat of primer applied. All  $\frac{5}{8} \times 2$  and  $\frac{5}{8} \times 3$  redwood strips. Aluminum screen is 0.011-inch diameter wire in a  $\frac{1}{16}$ -inch mesh. Add \$60.00 for heavy-duty mesh, \$50.00 for extra bracing and \$100.00 for galvanized frame.

The heavy mesh (0.025 inch diameter wire,  $\frac{1}{8}$ -inch mesh) is about  $2\frac{1}{2}$  times as heavy as the regular mesh and will withstand abuse by hail, ice, etc. much better than the regular mesh. The extra bracing is necessary if you plan to move the antenna about. It makes the framework very rigid.

The 12-foot 8-Ball with galvanized frame, heavy mesh and extra bracing is a commercial-grade antenna named "Octasphere" and is available for \$1195.00. Feed horn (fits LNA with WR-229 input): Sheet metal with brass flange, \$40.00; Aluminum \$60.00. RG-213 cable (loss 25 dB/100 feet at 4 GHz), \$0.50 per foot. FM-8 cable (loss 13 dB/100 feet at 4 GHz), \$0.60 per foot. Avantek 120° LNA (50 dB gain) \$690.00 including DC block; \$650.00 without DC block. All prices are FOB, Salem, AR.

the very top and bottom strips. Those will be about  $\frac{3}{4}$ -inch closer in.

Now attach the adjustment bolts to the  $\frac{3}{4} \times 3$ -inch vertical wood strips (except for the adjustment bolts at the ends of the two outermost strips) using the bolt lengths shown in Fig. 5. Note that the 8- and 12-inch bolts are actually

*continued on last page*



# BUILD THIS

**Part 2** ALTHOUGH YOUR 8-Ball antenna is starting to look like the finished product, we'll finish the lattice and install the screen.

Before installing the adjustment bolts in the ends of the two outermost vertical strips, cut a piece of  $\frac{1}{4} \times 2$ -inch strip long enough to reach across the corner adjustment bolts. Drill a hole at each end to match the position and size of the adjustment bolts and install as shown in Fig. 10.

Cut another piece of  $\frac{1}{4} \times 2$ -inch strip to fit cross the corner in between the vertical strips and install it across the corner between the vertical strips. It must be on top of the first diagonal-corner strip and underneath the horizontal strips as shown in Fig. 11. Finish across the corners and down the sides with  $\frac{1}{4} \times 2$ -inch filler strips cut from scrap and installed as shown in Figs. 12 and 13 respectively. Those filler strips are necessary in order to do a good job of stretching the screen. Attach all short pieces with brass wood screws. Trim off the excess ends of the strips with a saw and tighten all of the adjustment bolts. That completes the frame and lattice, and the assembly should look like Fig. 4.

## SATELLITE TV ANTENNA

*In this part, we'll complete the assembly of the basic 8-Ball antenna and begin to get it ready for mounting.*

### Installing the screen

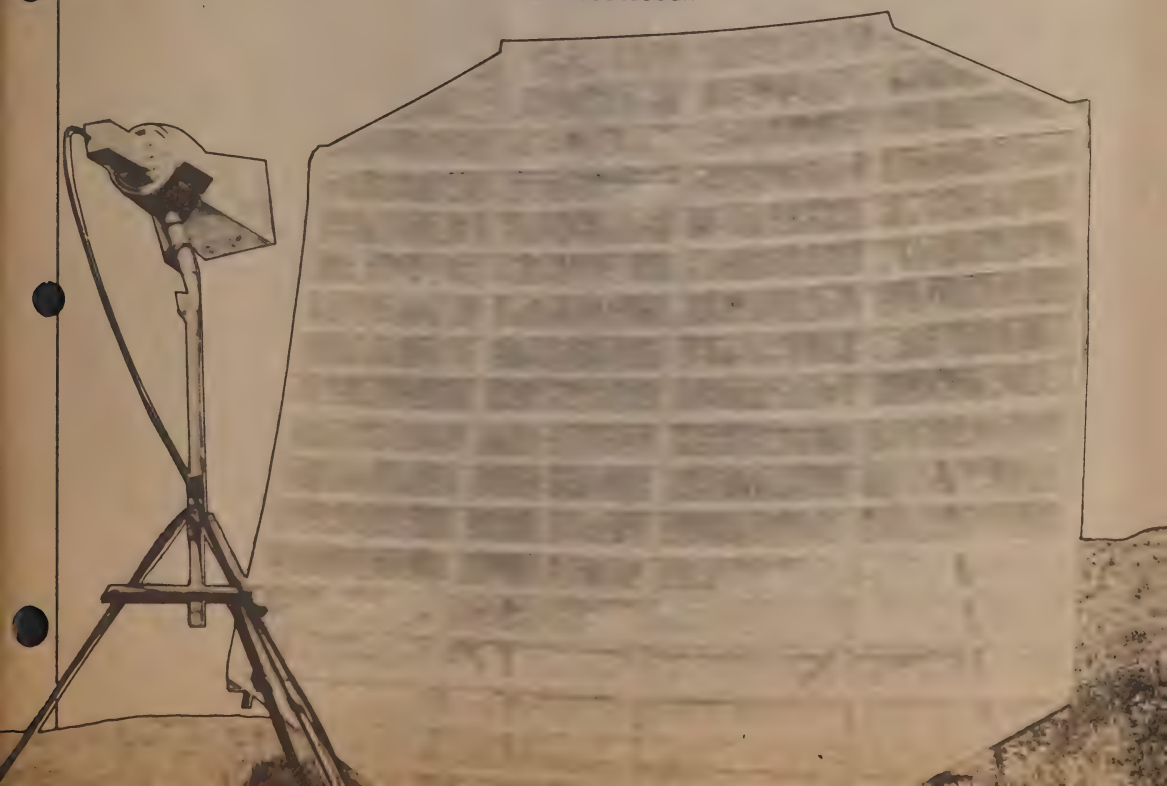
Study the assembled frame from all angles, making sure that its curves are uniform. Be sure that all adjustment bolts are secure.

Up to now, we have not needed to do any precision assembly. However, the screen **must** be installed properly (meaning good and tight). If possible, move the antenna close to the spot where it will be located before beginning.

Start rolling out the first run of screen so one edge is on the middle horizontal strip of the lattice (Fig. 14). The screen is 26 inches wide. That allows for a good overlap as the screen runs repeat every 24 inches. There are six runs of 12 feet each—requiring a total of 72 feet of material.

Align the screen so that one overlap falls on the middle horizontal strip and another overlap falls on the third strip up (all overlaps should be equal). Leave equal overhangs at the ends. Use  $\frac{1}{4}$ -inch or  $\frac{1}{8}$ -inch long rustproof staples—whichever works best in your staple gun. The staples should drive into the wood far enough to hold the screen snugly—without going in far enough to cut the screen. Start with four or five staples in the center of the antenna at

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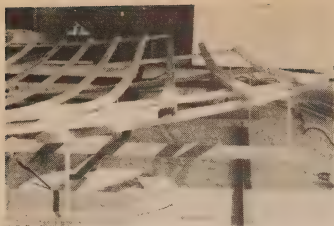


FIG. 10—A PIECE of  $\frac{3}{4}\times 2$ -inch stock, long enough to reach across the corner bolts, is installed in each corner as shown.

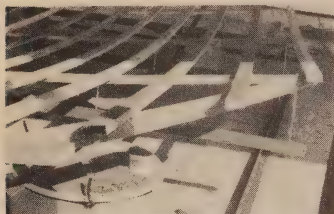


FIG. 11—ANOTHER PIECE OF  $\frac{3}{4}\times 2$ -inch stock, is installed on top of the first so it is even with the vertical strips.

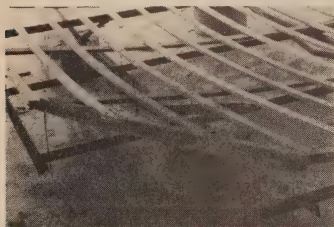


FIG. 12—MITERED STRIPS, cut from  $\frac{3}{4}\times 2$  scrap, are fitted between the ends of the horizontal strips so that the frame edge is level for attaching the screen.

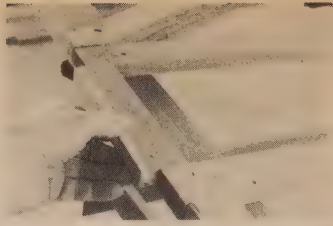


FIG. 13—SHORT PIECES OF  $\frac{3}{4}\times 2$  are cut to fit between the ends of the horizontal ribs in the lattice. They also provide an even surface for attaching the reflector screen. Brass screws hold each piece in place.

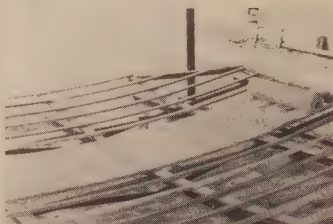


FIG. 14—START COVERING THE FRAME by rolling out the screen in a strip with one edge overlapping the center horizontal lattice strip.



FIG. 15—KEEP TENSION ON THE SCREEN as you place the staples until you have tacked all around the edges. When working with the first strip of mesh you will have to stand between slats in the lattice.



FIG. 16—AFTER STAPLING ONE EDGE, keep the screen taut and staple the point directly across from the first.

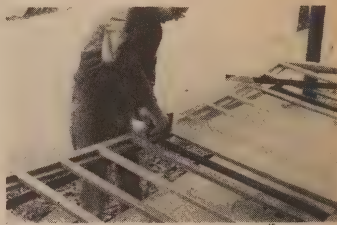


FIG. 17—PULL THE ENDS tight enough to keep the screen straight from center to edge. But, don't pull too tight—the screen may pucker in the middle.

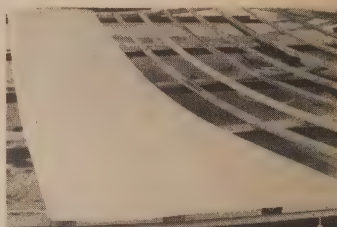


FIG. 18—ONE STRIP OF SCREEN completely anchored in place. When you've finished there will be one staple about every three inches.

one edge of the screen (Fig. 15). Pull tightly **straight** across and staple the other side as shown in Fig. 16. Now, put three or four staples into each of the two strips in between.

Go to one end of the screen and pull it tight enough to cause it to "stretch" straight across from center to the edge. **Don't pull the screen too tight**—that will make it pucker near the middle! Again, staple one edge first, then stretch the screen tightly and staple the other corner. Now, pull the screen toward you hard enough so it has uniform tension and add several staples across the end of the screen (see Fig. 17).

Halfway between one end and the middle of the screen run, pull the far side of the screen away from you a bit ( $\frac{1}{4}$  to  $\frac{3}{8}$ -inch is OK), and put in four or five staples. Pull the screen tight and add four or five staples directly across from those you just put in. Now, staple the screen to the strips in between.

Move to a point halfway between two previously stapled points, put a staple in one edge, and then pull the screen di-

rectly across from that staple and add another staple. Continue until the entire run of the screen has been stapled in place. Don't skimp, use one staple every three inches near each side of each wood strip. Figure 18 shows one run of screen firmly stapled in place.

Install the remaining five runs of screen the same way.

Next we'll show you how to cut and install the rear legs and braces. We recommend that you don't do that part of the construction at this time since the length of the rear legs depends on your location relative to the location of the satellite(s) you wish to receive. (Complete information on how to aim the antenna will be given next month and you'll be able to proceed then.) For now, put the antenna up on blocks so it doesn't warp.

Figure 19 shows the legs and braces that support the antenna. Prepare rear legs RL1 and RL2 by attaching rear-leg extensions RLX to get the desired tilt angle. If you are not working with a kit,

you'll have to drill holes in VR2, VR4, RL1, RL2, and leg extensions RLX. Drill four holes in VR2 and VR4 (see Fig. 20-a). Above the center line, drill holes at 4 inches and 48 inches. Below center, drill holes at 48 inches and 68 inches. In RL1 and RL2 drill holes 1 and 48 inches from the top end and 1, 3, and 5 inches from the bottom (see Fig. 20-b). Use special care in spotting the holes drilled and remember that you will have right- and left-hand members. Drill  $\frac{1}{4}$ -inch holes 2 inches apart along the length of RLX. Drill holes in braces B6  $\frac{1}{4}$  inch apart for 12 inches from one end.

The tilt angle and base pad dimensions (see Table 1) are determined by your longitude and latitude, and the satellite(s) that you want to receive. That will be covered in detail next month.

Move the antenna off the support blocks and place two short 2x4's (or blocks) under the BF base across the bottom of the antenna to prevent bending the bottom row of adjustment bolts. Raise the top of the antenna three or



# HOW THE 8-BALL GOT ITS SHAPE

The reflector most often used in TVRO (TV Receive-Only) antennas is shaped like a parabola as shown in Fig. 1. Its design is based on the

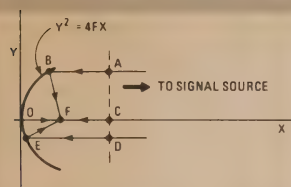


FIG. 1

equation  $y^2 = 4fx$  where  $f$  is the distance from the center of the antenna to the focal point. A characteristic of the parabolic shape is that all signals from far away will be reflected to the focal point. This assumes that the antenna is pointed exactly toward (bore-sighted at) the signal source.

A second characteristic of the parabola is that the distance traveled from point A to point B to point F is the same as the distance from C to O to F and from D to E to F; with points A, C, and D lying on a line parallel to the Y axis. In that case, all signals reaching the focal point are in phase with each other and add together, no matter what part of the dish they are reflected from.

A horn is generally used to couple the signal at the focal point to the LNA waveguide. Its size is selected to match the F/D ratio (focal length: diameter) of the reflector. Most TVRO antennas have a F/D ratio in the range of 0.3 to 0.5. A 12-foot parabola with a 0.4 F/D ratio would be about 22½ inches deep.

The reflector surface of the 8-Ball is spherical rather than parabolic. It is like a 12-foot-square section cut from the surface of a sphere (ball) 60 feet in diameter (see Fig. 2). The

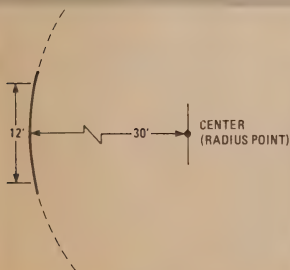


FIG. 2

depth of the 8-Ball reflector is about 7¼ inches (7.27347 inches, to be exact). On the other hand, if a 12-foot parabolic antenna were built with a 15-foot focal length it would be 7.2 inches deep. Thus, the difference between the surface of the

spherical antenna and a true parabolic antenna is only about ¼ inch (about 0.025 wavelength at 4GHz), and that much difference only occurs at the extreme edges of the antenna. The difference is much less at most points on the reflector surface.

There are, however, several practical advantages to the spherical reflector. One is that it can be easily checked for accuracy using a simple 30-foot radius-wire. Remember all points on the surface are the same distance from the radius point. Another advantage is that, being spherical, the curve is the same all over the dish. That means, that for the amount of curvature in the 8-Ball, it will function with good efficiency even if it is aimed to a point as much as 15 degrees either side of the exact location of the satellite (or up to 20 degrees in most areas of the U.S.). Thus the spherical dish can be used to receive signals from more than one satellite at a time, so long as the difference between the look-angles of the two (or more) satellites is less than about 30 degrees—although the difference in look-angles can be as much as 40 degrees in areas with strong signal levels.

A very useful advantage of this antenna is the fact that the reflector can be mounted in a fixed position and all satellites with look angles up to 15-20 degrees on either side of the bore-sight direction can be received simply by moving the feed horn to the proper focus point. This is shown in Fig. 3. Use two or more LNA/feed horns if you would like to receive two or more satellites simultaneously.

Still another advantage of the spherical reflector is that for elevation look angles of 30° or less, if you tilt the 8-Ball back from the vertical an amount equal to half the look angle, the focal point will be level with the center of the dish or about six feet off the ground (Fig. 4-a). That is a convenient height for the feed horn—particularly if you plan to shift the feed horn about to receive several satellites. (If it is necessary to have the feed horn lower than the center of the dish, you must cover the opening with something to keep the rain out because in that position, the horn is

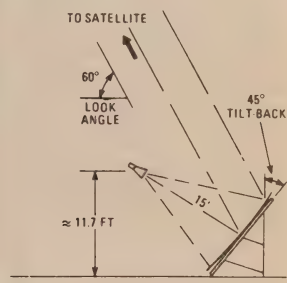
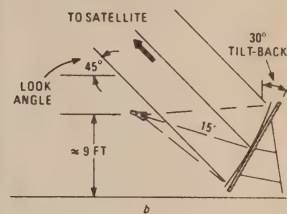
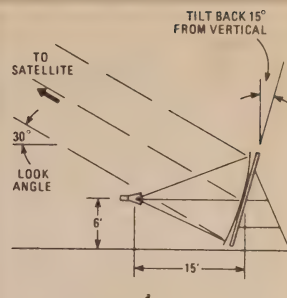
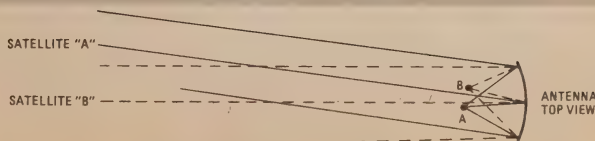


FIG. 4

pointing up toward the center of the antenna.)

For elevation look angles of over 30 degrees, the feed horn must be mounted higher off the ground because you shouldn't have more than 15 degrees difference between the satellite look-angle and the pointing angle of the dish. Figures 4-b and 4-c show how the feed horn height must be increased as the elevation look angle increases. In those cases, the tilt-back angle is 15 degrees less than the look angle. **R-E**



NOTE: FOCUS POINT IS 15 FT. FROM CENTER OF DISH.

FIG. 3



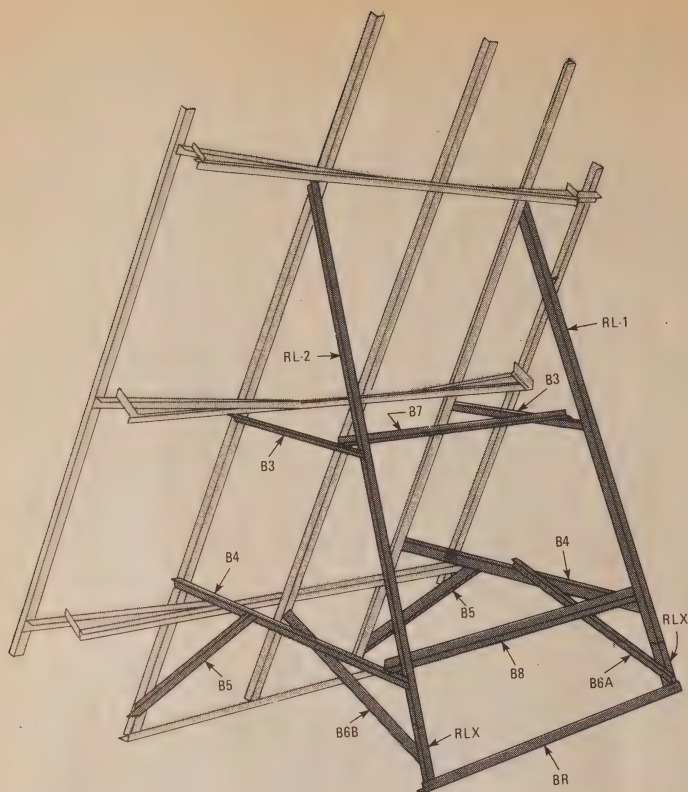


FIG. 19—THE REAR LEGS and the braces set the tilt of the reflector surface. Tilt is adjusted by lengthening or shortening the rear legs.

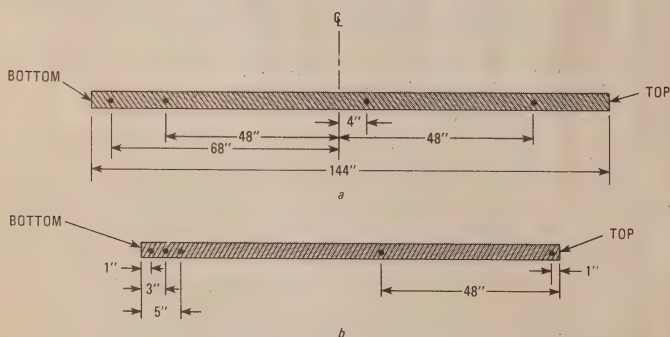


FIG. 20—DRILL HOLES in VR2 and VR4 as shown in a. The holes in RL1 and RL2 are drilled as shown in b.

TABLE 1

Antenna Tilt Angle (Degrees)	RL Length	Base Pad Dimensions	
		(A)	(B)
6	11' 7"	7' 0"	8' 2"
8	11' 4"	6' 11"	8' 1"
10	11' 1"	6' 9"	8' 0"
13	10' 7"	6' 6"	7' 11"
17	10' 1"	6' 4"	7' 10"
21	9' 7"	6' 2"	7' 9"
26	9' 1"	6' 0"	7' 8"
31	8' 7"	5' 11"	7' 6"
37	8' 0"	5' 9"	7' 4"



FIG. 21—THE TOP END OF THE ANTENNA is raised three to four feet off the ground so rear legs RL1 and RL2 can be attached. Put small blocks under the lower end to protect the corner adjustment bolts.

four feet off the ground and attach rear legs RL1 and RL2 as shown in Fig. 21.

Raise the antenna into place. The rear legs will slide into place. BE VERY CAREFUL when raising or moving the antenna until it is secured on the base pads. It can twist out of shape if one side is lifted more than the other. That can cause the screen to stretch and become loose. NEVER stand the antenna up until you are prepared to anchor it securely. It will blow over if the wind speed is 20 to 30 mph from the rear.

Install braces B3, B4, B5, B6, B7, B8, and BR in the order listed (see Figs. 19 and 22). The antenna is now complete and ready to be placed on the base pads.



FIG. 22—REAR VIEW of the 12-foot 8-Ball antenna. All of the rear-support members are clearly visible.

That finishes the assembly of the basic 8-Ball antenna. Next month we'll show you how to find the satellites that you're interested in, pour the concrete basepads, mount the antenna, and adjust the reflector for best reception. R-E



# BUILD THIS

## SATELLITE TV ANTENNA

Now that you've built the antenna, you have to set it up and aim it in the right direction. This month we'll show you everything you need to know to complete the project.

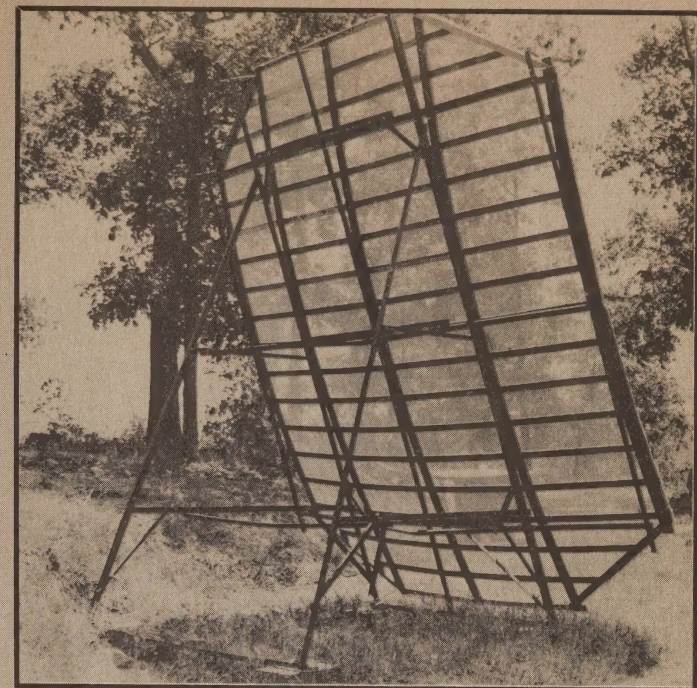
BY H. D. McCULLOUGH

**Part 3** BEFORE INSTALLING the 8-Ball, you need to know where the satellites that you're interested in are located relative to where you live. That information is needed to position the antenna properly.

### Positioning the antenna

Using the graphs in Figs. 23 and 24, and Table 2, you can determine the elevation and azimuth from any location to any satellite. To use the graphs, you must know your longitude and latitude, and the longitude of the satellite. Table 2 shows the positions of the satellites in the Clark belt.

After determining the look-angles (elevation and azimuth) to the satellite(s) desired, you must set the base pads for the necessary azimuth heading. Figure 25 shows how the pads are positioned, and Table 1 (p. 62, Sept. issue) gives the front-to-back and side-to-side dimensions. Pour concrete piers or pads 1 foot square and 2 feet deep (more in loose soil). Set 10-inch long, 1/2-inch anchor bolts to project 2-3 inches above the surface. (Note that the rear pads are spread farther apart than the front ones. The front pads are 5 feet, 8 inches apart; the rear ones from 7 feet, 4 inches to 8 feet, 2 inches.) Figure 26 shows how the antenna is



anchored on the pads.

If you are primarily interested in receiving signals from one satellite, then face the antenna toward the azimuth heading of that "bird" and, for elevation look-angles of 30 degrees or less, tilt the antenna back from the vertical an amount equal to *half* the elevation look-angle of that satellite. The focal point (and the horn/LNA location) will be 6-feet high and directly in front of the dish. (Refer to Fig. 4-a in "How the 8-Ball Got Its Shape", P. 61 in the September issue)

For elevation look-angles greater

than 30 degrees, tilt the antenna back 15 degrees *less than the look-angle*. (See Figs. 4-b and 4-c of "How the 8-Ball Got Its Shape" as mentioned above.) Figure 27 shows how the antenna's tilt angle can be checked using an inclinometer. The inclinometer is made using a protractor, string, and plumb-bob.

Once the reflector is positioned fairly close to the desired azimuth and elevation settings, find the satellite by pointing the feed horn directly toward the center of the dish, and then moving the horn up and down and side-to-side around the point where the focal point should be. The best focus (and best picture) will be about 15 feet from the center of the dish. That assumes that you have an LNA, receiver (down-converter), and TV set all properly connected. Place the TV set where you can see it while positioning the antenna feed horn.

If you want to receive more than one satellite, position the reflector midway between the azimuth headings and elevation look-angles of the two satellites that are farthest apart. Just be sure to be within 15 degrees of the bore-sight direction of the satellite you are primarily interested in.

See Fig. 28 for the focus-point locations for seven satellites. The heading

TABLE 2

Satellite	Location (Degrees West) Longitude
Comstar III	87
Westar III	91
Comstar II	95
Westar I	99
Anik I	104
Anik B	109
Anik III	114
Satcom II	119
Westar II	123.5
Comstar I	128
Satcom I	135



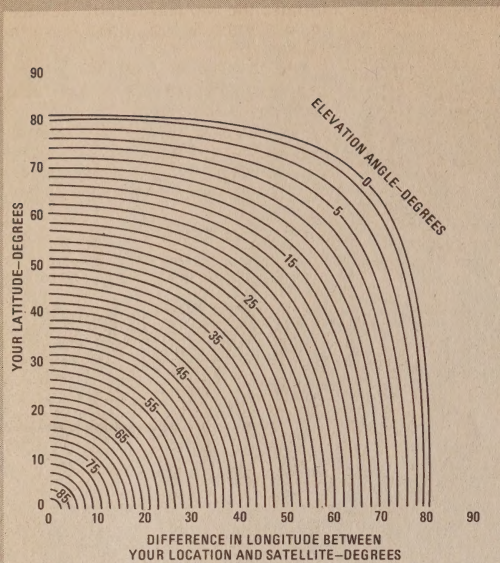


FIG. 23—ELEVATION ANGLE of the satellite can be determined easily by using this chart. Find the difference in longitude between the satellite and your location on one axis, and your location's latitude on the other. The point of intersection falls on a curve showing elevation angle.\*

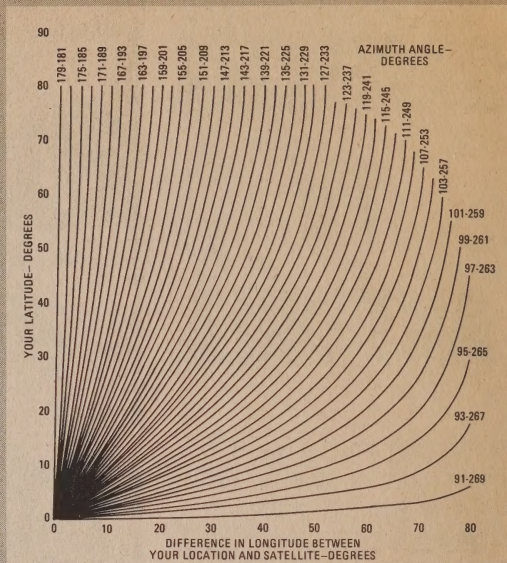


FIG. 24—AZIMUTH ANGLE is determined from this chart. The azimuth angles of 179 degrees and less are for satellites east of your location; angles of 181 degrees and up are for satellites west of you.\*

(azimuth) given (220 degrees) is only accurate for one location—northern Arkansas—but the relative positions of the focus points (Fig. 28-a) will be the same anywhere.

The elevation look-angle will be largest for a satellite that is due south of your location. Notice that the greater the elevation angle, the lower the focus point will be for any specific angle you have tilted back the dish. The satellites used in the example in Fig. 28 are all west of due south and the most westerly satellite (Satcom 1) gives the highest focus point. Notice also that to receive all seven satellites with maximum efficiency, the dish has to be tilted back enough to accommodate the satellite with the highest look-angle (30-degree tilt in this example to match Anik 1 which has a look-angle of 45 degrees). That results in the focus point for Satcom 1 (the lowest look-angle) being rather high off the ground.

For that reason, and the fact that our experiments required moving the LNA/feed horn around, the test antenna was oriented more toward Satcom I, with signals still received with good efficiency from Comstar I, Westar II and Satcom II. The signals from the Anik were

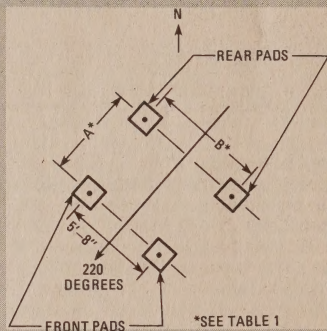


FIG. 25—MOUNTING PADS ARE POSITIONED according to the azimuth heading of the satellite you want. Here, the azimuth is 220 degrees, suitable for receiving satellites with azimuths from 205 to 235 degrees. \*SEE TABLE 1

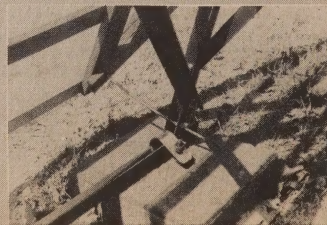


FIG. 26—CONCRETE BASE PADS support and anchor the four corners of the antenna. Anchor bolts and "J" clips secure the antenna to the pads.



FIG. 27—A SIMPLE INCLINOMETER (a protractor, string, and plumb-bob) used to check the tilt angle of the antenna. With the protractor against a vertical rib, read the angle where the string crosses the scale.

watchable, but not "clean." The problem of high off-the-ground focus points does not exist in the far Northern latitudes, where elevation look-angles are low for ALL satellites.

A feed horn is available from the supplier listed. If you decide to build your own, see Fig. 29 for the dimensions of the horn that gives the best results of all that we've tried. Ordinary galvanized sheet metal seems to work fine. Brass or silver may be better, but probably not much.

\*Figures 23 and 24 are reprinted through the courtesy of CATJ. They originally appeared in the November 1978 issue of that publication.



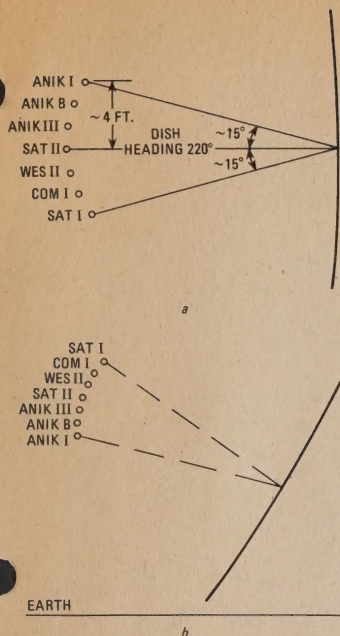


FIG. 28—HOW FOCUS POINTS ARE LOCATED: A top view of the antenna (a) shows the relative locations of the focus points for seven satellites. The side-view (b) shows the vertical position of the LNA horn for satellites.

A simple and inexpensive way to mount the LNA/feed horn is shown in Fig. 30. Attach the horn to the LNA and slip it inside a piece of 5-inch plastic pipe, 10 inches long. Secure it with any small brackets and spacers. Slip the 5-inch pipe inside a piece of 6-inch pipe, 12 inches long. Place soft spacers or pads between the pipes so that the inside pipe will rotate, but with enough friction to hold it in place. The assembly can be mounted on a board, with a motor attached to rotate the LNA for polarity selection.

### Final alignment

After the antenna is in place on the base pads, you should adjust it for a precise curve. A simple way to do that is to tie a radius wire to a point 30 feet directly in front of the center of the dish, then check the antenna surface near each adjustment bolt and adjust so that every part of the dish is 30 feet from the radius point.

A radius wire with a spring-loaded end is best for this. The spring-loaded

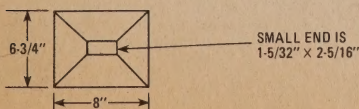


FIG. 29—FEED-HORN DIMENSIONS. Use these to build your own horn from sheet metal or a similar material.

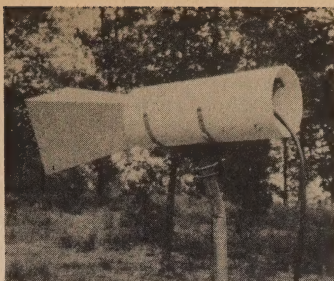


FIG. 30—THE LNA/FEED-HORN ASSEMBLY can be mounted inside a length of PVC pipe as shown here.

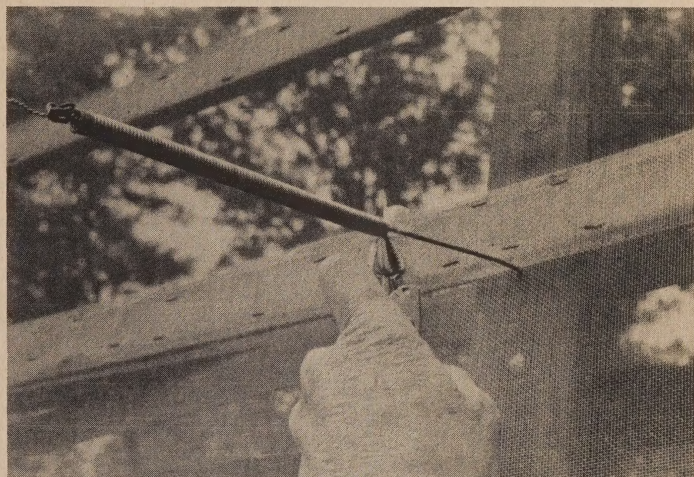


FIG. 31—RADIUS WIRE, 30 feet long, is used to check the reflector's curvature. Adjustment bolts are set so that all points on the surface are exactly the same distance from the radius point.

end is fairly easy to make. The prod is simply a piece of coat-hanger wire, about 15 inches long, with a loop at one end. The actual length of the prod is not critical as long as you remember that the total length of the radius wire and the prod should be approximately 30 feet. Slip a moderately-stiff spring over the hanger-wire prod and attach the spring and the radius wire to the loop as shown in Fig. 31. The spring makes it easier to hold a constant tension on the wire throughout the adjustment procedure; simply stretch the spring the same amount for each adjustment. A piece of tape can be stuck to the prod and used as a reference point as shown in Fig. 31.

To keep the spot where the radius point is tied from being too high off the

ground, it may be necessary to tilt the antenna forward. If you do that, be sure to raise the two rear legs by the *exact* same amount so you don't warp the antenna. Also, if you tilt the antenna to a near-vertical position, tie it down temporarily to prevent it from being blown over during the adjustment.

The radius point can be located by trial and error. First attach one end of the radius wire to a point about 30 feet (the exact distance is not critical as long as it is close) directly in front of the center of the dish—or as near the center as you can tell by looking. Then with the spring end, check across the

middle of the dish surface left to right to see if one side is closer to the radius point than the other. Move the radius point to the left or right as necessary to get the best "fit" across the dish. Repeat that procedure going from top to bottom, adjusting the radius point up or down for the best "fit."

Once the radius point is set, move each adjustment bolt in or out where the bolt goes through the frame so that the prod on the end of the radius wire just touches the screen when the spring is stretched to where it just touches the piece of tape on the prod.

It is important to take your time and do this right. With two people, you should be able to set the surface to within 1/16-inch in 30 minutes or so. If you have the dish tilted forward when you complete the adjustments, carefully lower it back in place and sight across the edge of the dish to make sure there is no twist in the surface. If necessary, put a shim under a rear leg.

Probably the easiest way to get the reflector surface out of "true" and lose the effectiveness of the antenna is to

*continued on last page*



threaded rods without heads and require a nut and washer on each side of the wood strip. Tighten the bolts and attach the vertical wood strip/bolt assemblies to the frame as shown in Figs. 5 and 6, using a 1/4-inch nut on each side of the metal rib as shown. Set the spacing between the vertical wood strips and the frame according to the dimensions in Fig. 5, but tighten the bolts just finger-tight.

For ease in setting the spacing between the rib and the redwood vertical strip, cut 13/16-inch, 37/32-inch, and 7/4-inch spacer blocks. Use them to set the spacings at points 24, 48, and 72 inches up and down from center. (See Fig. 5.) Figure 9 shows the 7/4-inch spacer in place while one of the 12-inch bolts is being adjusted.

It is very important to position the vertical strips so that the horizontal strips lie flat across them. That is why the adjustment bolts were left just finger-tight—to allow for the slight left or right movement necessary for alignment. Once the horizontal strips have been installed, the adjustment bolts will be tightened.

Attach the 3/4×2-inch horizontal wood strips to the vertical strips as shown in Fig. 4. At each lattice joint use glue and a 1 1/4-inch brass screw. Pre-drill the screw holes—preferably with a pilot drill—otherwise you're likely to break the screw or split the wood.

We'll show you how to handle the lattice corners when we continue with the 8-Ball next month. **R-E**

## PARTS LIST—FEED HORN

Galvanized sheet metal

PVC pipe, 5-inch diameter, 10 inches long

PVC pipe, 6-inch diameter, 12 inches long.

**Miscellaneous:** Soft spacers or pads (see text), hardware, etc.

The following are available from McCulloch Satellite Systems, PO Box 57, Highway 62-East, Salem, AR 72576: The 12-foot 8-Ball Satellite Television Antenna Kit, \$750. Includes everything except staples and concrete for mounting base. Frame is 1 1/2 × 1 1/2-inch angle iron with all pieces cut to fit and drilled. One coat of primer applied. All 1/2 × 2 and 1/2 × 3 redwood strips. Aluminum screen is 0.011-inch diameter wire in a 1/16-inch mesh. Add \$60.00 for heavy-duty mesh, \$50.00 for extra bracing and \$100.00 for galvanized frame.

The heavy mesh (0.025 inch diameter wire, 1/8-inch mesh) is about 2 1/2 times as heavy as the regular mesh and will withstand abuse by hail, ice, etc. much better than the regular mesh. The extra bracing is necessary if you plan to move the antenna about. It makes the framework very rigid.

The 12-foot 8-Ball with galvanized frame, heavy mesh and extra bracing is a commercial-grade antenna named "Octasphere" and is available for \$1195.00. Feed horn (fits LNA with WR-229 input): Sheet metal with brass flange, \$40.00; Aluminum \$60.00 RG-213 cable (loss 25 dB/100 feet at 4 GHz), \$0.50 per foot. FM-8 cable (loss 13 dB/100 feet at 4 GHz), \$0.60 per foot. Avantek 120° LNA (50 dB gain) \$690.00 including DC block; \$650.00 without DC block. All prices are FOB, Salem, AR.



**FIG. 32—TWO STRINGS**, installed after alignment as shown, make it easy to detect any warps in the reflector surface.

have one rear leg uneven with respect to the other. That causes a "twist" in the frame, and therefore, in the reflector surface. One way to check for a twist is to look at the antenna from the side and see if all the vertical ribs are parallel, or take an inclinometer and check each of the three middle vertical ribs. They should all have the same tilt angle.

Another, and perhaps the most accurate, way of making sure that the antenna retains its shape after it is aligned with the radius wire is to criss-cross a pair of strings as shown in Fig. 32. The strings must be installed after alignment, but *before* the antenna is moved. Install the strings from the top-right to the bottom-left corners, and from the top-left to the bottom-right corners. Adjust the strings as necessary so that they *just* touch at their centers. When you move the antenna, any twist will be apparent and can be quickly corrected by placing shims under one leg until the strings again just touch. **R-E**